MASTER

Turning digital technologies into business opportunities
A roadmap toward industry 4.0 maturity : Performed with IXON Cloud

Poels, Stijn

Award date:
2023

Department of Industrial Engineering

Master Innovation Management

Turning digital technologies into business opportunities: A roadmap toward industry 4.0 maturity

Performed with IXON Cloud

Master thesis - Stijn Poels

1514091

Supervisors:

ir. Annelies Bobelyn

ir. Alex Alblas

Final version

Eindhoven - 9th of March

Abstract

The German government and German’s biggest manufacturing companies introduced Industry 4.0 in 2011 as the fourth industrial revolution. Since then, it gained popularity in the manufacturing industry and has recently received recognition from SMEs. The implementation of Industry 4.0 technologies is expected to bring them significant improvements in productivity, quality, and safety, helping them to stay competitive in a rapidly changing business environment. Even though the benefits are proven for bigger OEMs, SMEs are still hesitant to adopt. The reason for this is that the investments are high, what makes SMEs unsure about their ROI. Although Industry 4.0 received quite some interests from SMEs, prior research mainly focuses on OEMs in general, where sparse research have described VCR and VCA for SMEs yet. Also, existing research treat Industry 4.0 as an overarching term and as a big step to be implemented, despite the fact that it consists of multiple technologies that need to be broken down into several steps and order of implementation. Especially for SMEs, it is important that this transition is separated into smaller steps and implemented in a larger time frame. Consequently, a misalignment appears between SMEs current product-based business and these new technologies. Therefore, this research aimed at exploring how SMEs can transform Industry 4.0 technologies into business opportunities for every step that is required to take. On account of the fact that less information about SMEs in this topic is available, a systematic literature review of prior research have focused on the broader scope of OEM in general. The first SLR found that the MM for Industry 4.0 in manufacturing consists of eight phases, ranging from "No digitalization" to "Automating". The second SLR have found various ways of creating and capturing value for each MM phase that was found. By combining the VCR and VCA concepts into the MM, an initial framework have arose. OEMs can use this framework to identify opportunities for each phase implemented. However, there was no evidence that these business opportunities are identical to the methods SMEs use. Therefore, an empirical research was performed to adjust the framework to fit the MM, VCR, and VCA to the TCP. In this research, TCP is a term that indicate SMEs that are participating as OEMs in the manufacturing industry. This study have explored the differences between business derived by TCP and OEMs in general. This research ensured that the initial framework was extended and validated in practice. This resulted in an overarching framework that guides TCP in recognizing opportunities and making a profit for each step they take in the Industry 4.0 MM.

Preface

It is with great honor that I could present my thesis report about business opportunities in Industry 4.0. I have worked on this report with great pleasure and spent my days well at IXON and at the TU Eindhoven. Due to the broad scope of my research, I have never worked so hard and much as this period. Hence, I am extra proud of the result of this research. Hopefully, IXON can use this research to guide their customers in their Industry 4.0 journey.

I would like to express my appreciation to everyone who has supported and motivated me throughout this thesis's research and writing phases.
Firstly, I would like to extend my sincere gratitude to my supervisor, Annelies Bobelyn, for her guidance and encouragement. I also want to thank Alex Alblas, my second supervisor, for the critical notes during the process. It has made me think about the matter and sometimes changing direction. Her knowledge and feedback have been fundamental in shaping my research and enhancing the quality of my thesis. I would also like to thank my supervisor from IXON, Maikel Wolters. Even though I was the first intern he guided in his career, he did it great. I want to thank him for his guidance during the process and for providing me with all the resources I needed. And above all, for the wonderful time at IXON.

Furthermore, I would like to thank all my colleagues and friends for creating a supportive and stimulating environment for me throughout my studies. I did not have that much time for my girlfriend and friends during this period, but I am sure that I will catch up. A special thanks go to Luke, who has been joining me every day from 8:00 (to be honest, 10:00) till 23:00 at the university. The only thing I blame him for is that he didn't teach me how to drink coffee.

I am also indebted to the participants who generously contributed their time and knowledge to make this research possible. Without their participation, this thesis would not have been achievable.

Lastly, I would like to thank my family for their support, and encouragement throughout my academic journey. Their belief in me has been a continuous source of inspiration, and I am genuinely grateful for their belief in me.

Table of Contents

List of Tables

List of Figures

List of Acronyms

This section elaborates on abbreviations and important terms that are frequently used during this research.

IT	Information Technology
OEM	Original Equipment Manufacturer (machine builders)
SME	Small and Medium-sized Enterprises
TCP	Target Customer Profile
MM	Maturity Model
VCR	Value creation
VCA	Value capture
IoT	Internet of Things
IIoT	Industrial Internet of Things
RFID	Radio-frequency Identification
IaaS	Infrastructure as a Service
PaaS	Platform as a Service
SaaS	Software as a Service
CMM	Capability Maturity Model
BPMM	Business Process Management Maturity
CMMI	Capability Maturity Model Integration
PSS	Product Service System
SLR	Systematic Literature Review
BM	Business Model
RQ	Research Question
IS	Information Systems
ERP	Enterprise Resource Planning
PDM	Product Data Management
CAD	Computer-aided Design
R&D	Research & Development
OT	Operation Technology
VPN	Virtual Private Network
PLC	Programmable Logic Controller
KPI	Key Performance Indicators
OEE	Original Equipment Effectiveness
AI	Artificial Intelligence
ML	Machine Learning
SLA	Service Level Agreement
HMI	Human Machine Interface

1.Introduction

Over the last few years, the world has faced the fourth industrial revolution (Maghazei & Zürich, 2017). After the first three industrial revolutions, the introduction of steam-powered machines, the start of mass production, and the use of IT for automation, the world is now shifting toward a digital economy (Björkdahl, 2020; Liao et al., 2017). As a result, the focus shifts from mass production with human-technology interaction to a fully autonomous factory with “smart” machines, the so-called industry 4.0 revolution (Lasi et al., 2014). Industry 4.0 was introduced in 2011 by the German government in cooperation with the German industry, which started this project to improve the productivity and efficiency of the German high-tech industry to sustain competitiveness in global markets (Madsen, 2019).

According to Frank et al. (2019), Industry 4.0 can be explained as a *“new industrial maturity level of product firms, based on the connectivity provided by the Internet of Things (IoT), where the companies' products and process are interconnected and integrated to achieve higher value for both customers and the companies' internal processes"*. IoT is a key enabler of industry 4.0, since it enables all devices within a company to communicate using a wireless network linked through Internet-based technology such as the Internet, Cloud, terminals, and other equipment (Lasi et al., 2014; Lu, 2017). This technology allows companies to get insight into their machines and the corresponding data. This raw data can be retrieved and translated into valuable data for improving the efficiency of machines, reducing downtime, cutting operational costs, and making organizational decisions. That leads to enhanced customer satisfaction and sustained competitiveness in the market (Sony et al., 2021). Although the benefits are proven, OEMs are still hesitant to adopt these technologies (Dalmarco et al., 2019). Several challenges arise when OEMs integrate digital technologies into their business. Firstly, high investment costs is a main challenge for implementing digital solutions, especially for SMEs (Agostini & Nosella, 2020). Secondly, extensive data extraction with highly connected data systems makes companies insecure about cyber-security. Thirdly, companies also lack knowledge, skills, and other resources for implementing Industry 4.0 (Sony et al., 2021). Lastly, OEMs are not able to change their business models with Industry 4.0 (Matthyssens, 2019). There is a lack knowledge because industry 4.0 is still unclear for OEMs, who do not know which route to take due to the enormous amount of technologies (Chauhan et al., 2021; Saravanan et al., 2022).
OEMs only see an opportunity to implement industry 4.0 technologies if the benefits exceed the abovementioned risks. Now most of them still struggle to create digital business models, transforming these benefits into profit. Thus, OEMs have to recognize business cases from successful companies before these undergo such a project. In order words, OEMs should first find an appropriate business case for their Industry 4.0 technology to run a healthy business. Two of the key concepts that define such a successful business case are “Value creation (VCR)” and “Value capture (VCA)”. Here, VCR count for the benefits and VCA ensures that these benefits are turned into profit. Adoption of Industry 4.0 falters when the abovementioned high investments can not be earned back (Bosman et al., 2020). Therefore, it is crucial to have an understanding how Industry 4.0 technologies can be transformed to business opportunities.

Although several researchers have investigated how business can be created with Industry 4.0, most of them describe VCA for Industry 4.0 as implemented in one big step. This is not in line with the given that Industry 4.0 is a collective name of multiple technologies that can not be applied at once, but have to be implemented in smaller steps subsequently over a longer time frame (Santos & Martinho, 2020). This misalignment results in a lower ROI for OEMs since they are not able to return their investments back immediately after a new technology is implemented. This is even more important to know for smaller steps they take in Industry 4.0, because of the higher investments and less liquidity of a SME. The overall confusion by OEMs, and in particular SMEs, what Industry 4.0 exactly entails and how business can be generated in each step in the transition. Namely, SMEs do not have the skills and resources as bigger OEMs, resulting in other business opportunities. In the current literature, SMEs are missing an overview of VCR and VCA methods that can be applied to return their investment back. This research should make clear what is required to reach a certain phase and emphasize what it brings them in each smaller step. Hence, there is a need for a comprehensive framework where SMEs can identify opportunities to generate revenue for each step within Industry 4.0 that they implemented. Firstly, it is necessary to get an understanding in which phases within Industry 4.0 value can be created and captured. Therefore, a Systematic Literature Review (SLR) is executed to examine existing research to define the Industry 4.0 maturity model for OEMs in general and adjust it to serve as a basis for VCR and VCA concepts. A second SLR is executed to synthesize and link VCR and VCA concepts for every phase in that Industry 4.0 maturity model established before. Thereafter, interviews are executed to extends and validate the initial framework obtained. It enables either to validate the insights found in theory, and either to specify the framework to TCP. This enable them to transform their current business so that revenue can be derived from Industry 4.0 technologies.

1.1. Research project

This research is based on a research project with the customers of IXON Cloud. IXON Cloud is a company in the Netherlands that develop remote access and IoT solutions accessible for OEMs (OEMs) in various industries, such as health, packaging, agriculture, and food. IXON provides an end-to-end solution with hardware and software that enables remote access to the machines in a factory. It can also extract and visualize data from machines. With this data, the OEM can recognize problems faster, solve problems remotely, and optimize their machines in the future (Gupta & Rastogi, 2021). However, IXON sees that OEMs are hesitant to adopt Industry 4.0 technologies since they do not see the advantages and cannot earn their investment back. This research may help IXON to convince OEMs adopting Industry 4.0 by showing OEMs in which way value can be created and captured for a particular phase that the OEMs wants to go to.

1.2. TCP

The target population of IXON is described by the term “Target Customer Profile (TCP).” IXON uses this term to scope their customers. For IXON, their TCP is limited to small and medium-sized enterprises (SMEs) in the manufacturing industry. More specifically, these are small and medium-sized OEMs. OEMs (Original Equipment Manufacturer) use subsystems from other companies to build end products. These machines are sold to the end-user, who are primarily factories. These SMEs range from 10 to 250 employees, as stated in the European norms (European Commission, 2003). IXON targets these companies because SMEs mostly do not have the right resources to develop their own Industry 4.0 solution, where larger companies can develop these themselves (Marian & Hamburg, 2012).
IXON Cloud delivers such Industry 4.0 solutions to TCP in Europe. The subsystem that IXON delivers to OEMs is a router and a platform that allows TCP to use remote access or extract data from their machines. The TCP In the course of this report, the term TCP is used to describe the target customers of IXON, who are small and medium-sized OEMs (SMEs).

2. Problem identification

2.1. Research gaps

IXON Cloud sees that most OEMs do not know how value can be translated into revenue, while the investments are high on multiple aspects. Even though, lots of research has been describing business models for Industry 4.0. Two aspects in a business models that are inherent to each other are VCR and VCA. Most of the research focuses on one general method that can capture value for Industry 4.0 as a whole, which is too generalizable for this revolution's widespread range. For example, the research of Agarwal et al. (2022) describes that outcome-based, performance-based and value-based pricing business models have emerged by the rise of Industry 4.0. However, a OEMs takes several steps in this revolution incrementally. That makes it even more complex when it is unknown that value can be created and captured anywhere in the process. These VCR concepts are essential for manufacturers to understand the value of Industry 4.0 and how these value can be translated to revenue. A few researchers describe how value can be created for these single aspects in the industry 4.0 revolution. However, there is yet no research that describe how value can be created and captured for every phase in Industry 4.0.

Gap 1: OEMs are lacking knowledge on how value can be created and captured for every phase of the Industry 4.0 revolution.

To specify VCR and VCA for every phase in the Industry 4.0 revolution, a MM have to be developed first that could represent the corresponding VCR and VCA concepts. A MM can specify which phases OEMs face from zero to complete digitalization. Although numerous MMs are developed in this domain, most have their own specifications. MMs are developed to serve several purposes, such as an assessment or as a roadmap. MMs used as an assessment are also called readiness models. These are used to assess companies on a set of specifications. An example of such an assessment method is the model of Schumacher et al. (2017). However, these MMs are unsuitable for this research since it does not provide a roadmap and does not serve as a basis for VCR and VCA concepts. Industry 4.0 can also be used in several industries, such as building management, smart homes, or manufacturing. Even within the discipline of manufacturing, it can be used for supply chain, organization, or machinery. Furthermore, a MM that serves as a basis for business models have to be technologically-oriented or process-oriented. That is, the MM phases should have clear technological key concepts. To illustrate, one can develop VCR and VCA concepts on “condition monitoring” and “AI”, in comparison to “leadership competences”. That is because current research on business models bases VCR and VCA are grounded on technological aspects or process aspects at first. To illustrate Passlick et al. (2020) describe that forecasting can be captured with a subscription.

Gap 2: No research describes an Industry 4.0 MM that can serve as a basis for VCR and VCA concepts.

Furthermore, limited information is known about Industry 4.0 MMs for SMEs. Also, no research describe how SMEs can create and capture value with these technologies and how this differ from the way larger OEMs derive business. That may be crucial to investigate because SMEs do not counter similar problems as big companies (Mittal et al., 2018). Just about all SMEs lack a strategic vision and thus struggle to recognize technological trends on time (Eckelt et al., 2016; Placzek et al., 2015). Furthermore, they lack the resources to hire skilled workers (Cherchione & Esposito, 2017; Karre et al., 2017). SMEs report that they lack the necessary knowledge to implement these technologies (Sayem et al., 2022). These findings may imply that MMs and business models differ between large corporations and SMEs.

Gap 3: There is no evidence that an Industry 4.0 MM for OEMs in general follows the same steps as the MM for SMEs (TCP).

Gap 4: There is no evidence that the VCR and VCA concepts described in the literature also apply to SMEs (TCP).

2.2. Research questions

The problem identification has led to the main research question:

How can TCP transform Industry 4.0 technologies into business opportunities for every phase in the Industry 4.0 roadmap?

The main research question has been split into four sub-questions, answering the research gaps identified before. At the same time, these sub-questions support answering the main research question:

1. How does theory define the current Industry 4.0 MM for OEMs that could serve as a basis for VCR and VCA concepts?
2. How does theory describe how OEMs could create value for themselves and end-users in every phase of the Industry 4.0 MM?
3. How does theory describe how OEMs can capture value for every phase in the Industry 4.0 MM?
4. How can the initial framework be adjusted to enable a good fit for the TCP market?

This study is structured as follows: Firstly, the key concepts of this study are described in the Theoretical background. This is followed by two Systematic Literature Reviews (SLRs). SLR 1 investigates which phases in the MM are applicable to this study and how value can be created in these phases. Secondly, SLR 2 investigates how value can be captured in each of these phases described in SLR 1. Lastly, empirical research is conducted to solve the research gaps discovered in the literature and verify the framework in practice. The empirical study applies to a research project within IXON Cloud.

3. Theoretical background

This section describes the key concepts that are dominant throughout this study. This study focuses on creating a framework where VCR and VCA are described for every stage in the Maturity Model. The main topic of this research is grounded in *Industry 4.0*, which is an overarching term that describes the revolution of digital technologies that are central to this research. Herein, *IIoT* is an important concept and a key enabler in the industry 4.0 revolution that describes the overarching technology enabling connectivity between assets that enable communication and data collection. Due to the enormous amount of technologies, OEMs are unable to recognize the roadmap towards Industry 4.0 maturity. Therefore, a *Maturity Model (MM)* is used. It describes the current status of an OEM in this transition. These models are widely known in literature and used to assess companies based on a roadmap. Due to this unawareness, OEMs do not yet know how to *create value* for each technology. Consequently, OEMs do not know how to offer value to the end-user. *VCR and VCA* are key drivers ensuring these technologies will be valuable for the OEM. Recognizing the value may help OEMs to transform their technologies into business opportunities.

3.1. Industry 4.0

Industry 4.0 was initially developed for the German manufacturing industry to transform into a digitalized industry where products and processes are digitally connected by IoT (Frank et al., 2019). The first technology that was based on connectivity started 15 years ago with the so-called RFID chip, which was developed to store information from a distance with the help of radiofrequency. Since then, the scope of digitalization has become much further with new technological improvements beyond the scope of RFID (Wortmann & Flüchter, 2015). That enables the transition from a factory with stand-alone machines, to a factory with all connected machines. It involves the digitalization and implementation of IoT for industrial applications. The so-called industry 4.0 revolution is driven by various internet-based technologies, which can be seen in figure 2. The Internet of Things (IoT) is a concept that is a crucial enabler in the transition to Industry 4.0 (Zawra et al., 2017). It describes the collective name of various technologies that are based on the Internet. The Internet of Things Global Standards Initiative (IoT-GSI) defines IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting physical and virtual things based on existing and evolving interoperable information and communication technologies" (ITU, 2022). It describes the linking of different devices, which enables controlling the device and collecting, monitoring, exchanging, and analyzing the data that is retrieved from the devices.

In an industrial context, IoT is also called the IIoT (Industrial Internet of Things). IIoT is inherently linked to IoT but is more focused on collecting and analyzing data to optimize machines' performance, efficiency, and productivity and create economic benefits (Javaid, 2021; Khan et al., 2020). Moreover, it can be used to enable remote access to control machines from anywhere around the world. Therefore, it makes it possible to reduce the downtime of machines and the travel costs of the maintenance engineer since it can be directly fixed off-site (Gupta & Rastogi, 2022). Many industries have already adopted Industry 4.0 to create incremental value and economic benefits by improving transportation, maintenance, distribution, and service (Xu et al., 2018). For now, more and more industries and solution providers are identifying the benefits of Industry 4.0 (Javaid et al., 2021).

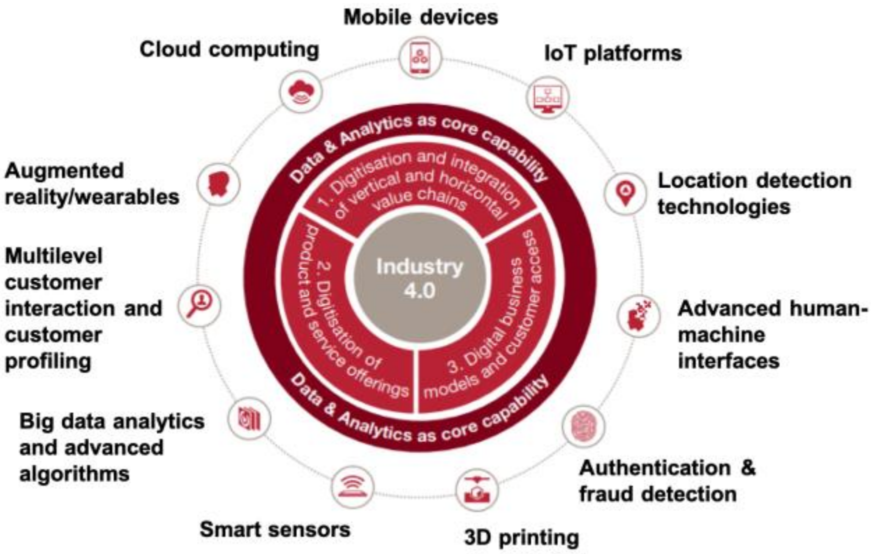


Figure 1: Global overview of Industry 4.0 technologies (PWC, 2016)

The foundation of Industry 4.0 is composed of a global network infrastructure of devices that are connected, based on sensors, networks, and data processing techniques.

3.2. Maturity Model (MM)

OEMs need to know what steps must be taken to grow Industry 4.0 in their businesses since the requirements for Industry 4.0 are still unclear . Unawareness is a critical factor here (Sony et al., 2021). That is a typical characteristic of Industry 4.0 since it still has no consistent definition and yet no clear roadmap, wherefore it is hard to categorize firms on their digital capabilities and resources (Ghobakhloo, 2018; Saravanan et al., 2022). For that reason, various industries are struggling with strategy creation and positioning toward industry 4.0 (Gökalp et al., 2017). Hence, one specific tool is used extensively in practice for assessing an organization on its progress in a specific domain: A Maturity Model (MM) (Backlund et al., 2014). A MM is described in the literature as *"a structured collection of elements that describe the characteristics of effective processes at different stages of development"* (Wendler, 2012). It provides managers a handhold of the company's maturity level, what stage the firm would like to go to, and what is needed to go there (Schumacher et al., 2016). Here, maturity is referred to as "a state of being complete, perfect or ready" (Simpson & Weiner, 1989). However, in an industrial context, maturity refers to "the development of a specific ability or reaching a targeted success from an initial to an anticipated stage" (Mettler, 2009). The first MMs were initially developed by software engineering companies in 1970, but are now used in various industries for descriptive and prescriptive purposes (Rafael et al., 2020). De Bruin et al. (2005) states that in 2005, more than a hundred different MMs were already proposed. That can even imply that in 2021 innumerable MMs were developed in different domains. Currently, MM models are used in various domains that all have their perspectives and naming, such as the Capability Maturity Model (CMM), Business Process Management Maturity (BPMM), Capability Maturity Model Integration (CMMI), etc. (Röglinger et al., 2012). MMs in digital context can also be called Industry 4.0 Maturity Models, (I)IoT Maturity Models or Digital Maturity Models.

MMs enable organizations to create a path toward a particular end goal, help them decide whether and when to take action, and provide a basis for what should be done to reach a higher stage in the model (Ustundag & Cevikcan, 2018). These models have several advantages for organizations in management, support, sales, and marketing (Gill & Vanboskirk, 2016). First, it helps companies to determine their status quo using different managerial perspectives or domains (Asdecker & Felch, 2018; Backlund et al., 2014). Here, a snapshot of the organization at that point can be made based on specific criteria (Becker et al., 2009). Secondly, companies can compare themselves across business units and other organizations (Asdecker & Felch, 2018; Proença and Borbinha, 2016). Thirdly, prescriptive models can emphasize the domain relationships with business performance, enabling companies to determine a roadmap for development in this topic (De Bruin et al., 2005).

An MM ensures that a OEM is able to recognize what is required to fulfil a certain phase within the model, what is needed to get their and what the potential next steps are. The next section elaborates on the VCR and VCA methods that can be integrated in the MM. This makes that OEMs can not only see what is required to fulfil a phase, but also what it could bring them.

3.3. Value creation and Value capture

Several advantages arise with the Industry 4.0 revolution. Most of the benefits are grounded in maintenance and operation services. With Industry 4.0, services become increasingly important (Gaiardelli et al., 2021). A term that is frequently mentioned with Industry 4.0 is called servitization. Servitization was first mentioned by Vandermerwe and Rada in 1988 and comprised the shift from a goods-centered approach to a service-centered approach to deliver value from a combination of goods, knowledge, services, and support. Nowadays, servitization is frequently mentioned together with digital technologies, although these terms do not originate from the same domain. Many researchers argue that servitization and Industry 4.0 technologies go hand-in-hand with servitization, since they can completely transform business models in the way manufacturers deliver their products and enable new service-oriented BM’s (Paschou et al., 2020). Langley (2022) states that servitization will be delayed because of the complexity for managers in identifying opportunities in offering digital services, in combination with the sparse knowledge of those technologies. Servitization in Industry 4.0 may take many forms, such as utilization over a time period, quality control, guarantee of zero downtime, and many more. As a result, the service provider can enhance customer relationships, customize offerings and achieve long-term value (Charro & Schaefer, 2018). However, servitization with Industry 4.0 can only be beneficial for the OEM if these are able to create revenue from services. The benefits and revenues that can be obtained with servitization are explained by two concepts: Value creation (VCR) and Value capture (VCA).

VCR and VCA are two crucial parts of a company’s business model (Sjödin et al., 2020). Besides the value created for the end-user, it is even so important that the OEM and the end-user agree on the value created so that everyone gets a fair share in the outcome, which is called VCA (Sjödin et al., 2020). Baier (1969) defines VCR as the “capacity of a good, service or activity to satisfy a need or provide a benefit for a person or legal entity”. Other definitions for this are benefits or advantages. When the value is created, the customer is either willing to pay for the increase in value, or retain the less valuable option at a lower cost (Priem, 2007).
So, when the value that is created exceeds the point where end-users actually pay for the increase in value, value is captured. “VCA” is defined as “the process of securing financial or nonfinancial return from VCR” (Chesbrough et al., 2018). Other definitions for VCA are monetizing and incentivization.

However, VCA should be viewed as distinct from VCR. Owing to the fact that the source which created value may not be able to capture value at the same time (Lepak et al., 2007).
One of the biggest challenges for SMEs in the Industry 4.0 revolution is that VCR can not be transformed into VCA. The problem is not the digital technology itself, but the transformation of a OEMs’ business model so that Industry 4.0 will be profitable (Almeida et al., 2020). As such, OEMs face difficulties in incentivizing the value that is created for the end user. OEMs still do not know how to offer certain technologies to their customers by transforming a core product into a PSS (Product Service System). A PSS is a combination of products, services, and infrastructure that helps to be competitive in several aspects, such as satisfying customer needs, being

competitive, and increasing sustainable goals. PSS that are offered in an industrial setting must enable service providers to concentrate on machine performance and availability so that the end-users can focus on their core competencies, making products. Although, the tasks that are taken over from the end-user are only financially viable if the service costs are lower than the perceived value of the PSS (Charro & Schaefer, 2018). Even though firms recognize the possibilities, it is still unclear how they can enable a servitized business model by integrating Industry 4.0 into their product-based businesses (Suppatvech et al., 2019).
Now that the technology is widely available, managers have to find out how the technological potential can be translated to economic value. Hence, the focus shifts from a simple technological issue to a managerial and strategic issue (Ehret & Wirtz, 2017). Consequently, a transition has to take place in order to change the businesses of OEMs (Paiola & Gebauer, 2020). Those business models that include digital technologies are the so-called digital business models, which point out to companies where "digital technologies have fundamentally affected the way a firm structure and carry out its business and thereby create and capture value for customers, the firm itself, and its partners" (Verhoef & Bijmolt, 2019). Specifically, Agostini and Nosella (2021) state that managers are emphasizing the VCR part of digital BMs and neglect the VCA part.

Conclusively, Industry 4.0 technologies open chances to change from a product-based company to a service-oriented company. However, the value created cannot be translated into business opportunities. A crucial step here is to capture the value that is created. Here the technology is available, but the problem lies on the managerial and strategic side. This means that OEMs should reshape their businesses to make a profit out of Industry 4.0.

4. Research design

A research design describes the methodological foundation of a study. It provides a systematic background that ensures the research is understandable and repeatable for the reader. This section elaborates on the research concepts that were chosen. This study's research design builds on two *Systematic Literature Reviews (SLRs),* followed by an *Empirical study*.

The first method used was an SLR that answered the first three research questions. The different subjects of the research questions ensured that two subsequent individual SLRs had to be conducted, SLR 1 and SLR 2. The two SLRs are performed subsequently, where SLR 2 depends on SLR 1. The first SLR (SLR 1) examined several MMs to explore which MM phases could apply to this research. This answered the first research question (RQ1). The description of the MM phases explained how value could be created in each phase, which answered the second research question (RQ2). This is justified in the next section, “Explorative literature review”. This formed the basis for conducting the second SLR (SLR 2), which examined how value can be captured by OEMs in each of the phases discovered. That answered the third research question (RQ3). Integration of the three concepts enabled the development of the framework from the literature. Here, the MM formed the basis for the VCR and VCA concepts. After that, the framework was built. The VCR findings were aligned directly with the MM phases since these are found correspondingly. On the other hand, the VCA findings were carefully analyzed on their fit in the corresponding phases since these are found in a separate SLR. In this case, the VCA concepts could be linked directly to the MM phases by papers describing these for a specific aspect of a particular MM phase or indirectly by use cases described in SLR 2.

Empirical research was used to answer the last research question (RQ4): *How can the initial framework be adjusted to enable a good fit for the TCP market?*. Empirical research is applied in the form of interviews, which ensured that the literature in SLR 1 and 2 was tested in the market. It also ensured that the theory found for OEMs are specified to the TCP. The interviews were executed with the customers of IXON and also non-customers that fit the exact requirements as the TCP. This sample of participants could provide a realistic view of the market. In addition, one Industry 4.0 expert was included in the sample to provide a more knowledgeable and comprehensive view of the market.

Finally, the final framework was developed by integrating and validating the insights from the interviews with the framework from the literature. Figure 4 shows a schematic overview of the research design described above. The following sections describe how the SLR and interviews were conducted.

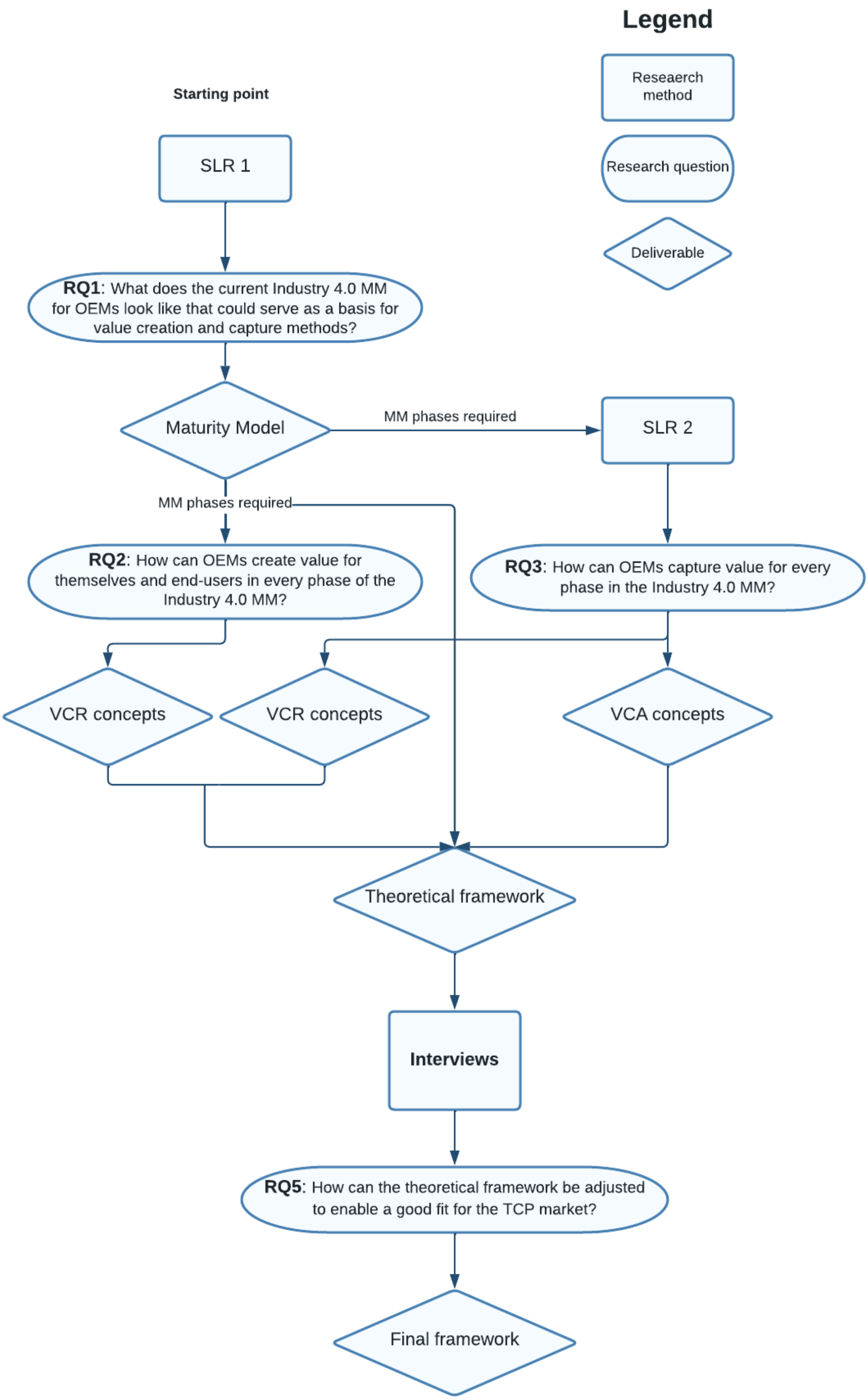


Figure 2: Schematic overview of the research design

4.1. Explorative literature review

Before the systematic literature was executed, explorative research was done to get familiar with the existing literature. Multiple databases were explored to identify which one could be valuable for research in the IS domain. Important concepts in this study were used in multiple databases to explore what the preliminary outcome of the SLRs could look like. Keywords such as Industry 4.0, maturity model, IIoT, SME, value creation, and value capturing were tried in different combinations. The papers that showed up brought two insights to consider before conducting the actual SLR.

Firstly, as described before, few studies focus on what phases in the MM apply to SMEs and how these companies can create and capture value with Industry 4.0. However, this small selection of papers does not provide sufficient information complete this SLR. Therefore, the target group in the SLR was initially broadened to all OEMs, instead of SMEs (TCP). This target group was further specified to the TCP later in the empirical research. Here, interviews are used to find out if the initial framework is different for TCP than for OEMs in general.

Secondly, two SLRs were conducted to answer the three research questions RQ1, RQ2, and RQ3. In the explorative research turned out that the papers in SLR 1, providing answers to RQ1, answered RQ2 as well. SLR 1 was initially intended to discover which phases apply to OEMs in the Industry 4.0 MM. However, most of these papers also comprehensively describe all the phases. It shows which characteristics have to change related to technology, process, people, and outcome. Here the outcome part shows what value is created when a phase is completed regarding these characteristics. Also, papers in SLR 2 that are specified to certain MM phases are describing VCR, which was later added to the VCR found in SLR 1. Thus, SLR 1 and SLR 2 provide sufficient information about VCR, which means an extra SLR investigating VCR would provide less extra knowledge to this research. As a result, an individual SLR answering RQ2 is not required anymore. That means that SLR 1 and SLR 2 count for answering RQ1, RQ2, and RQ3. The advantage of this approach, compared to an individual SLR, is that VCR is not described in general but already for every particular phase in the MM. This is a crucial requirement of RQ2 and contributed to the study's primary goal. This ensured a better fit for the VCR within each phase.
In conclusion, only SLR 1 and SLR 2 were executed, focusing on the research questions RQ1 and RQ3, respectively. The answer to RQ2 emerged from SLR 1.

4.2. Systematic Literature Review

The actual systematic literature review (SLR) is carried out after the exploratory literature review. The SLR made it possible to collect and analyze all extant literature on the themes included in this study. It provided a methodical approach to review the literature on the subject, allowing others to replicate the literature search and analysis. It is used to find and analyze pre-existing MMs, VCRs, and VCA concepts in the literature. Several scholars stressed the importance of an SLR and proposed methods for conducting them. This SLR adhered to the guidelines established by Wolfswinkel et al. (2013). This research consists of five steps that were carried out in the following order: *Define, search, select, analyze, and present.*

Define
In the first step, the criteria had to be set to include relevant literature for this study. The inclusion criteria for these SLRs are the database(s) used, publication period, publication types, and publication language. The choice of which database is used is vital to collect the right type and amount of research (Wolfswinkel et al., 2013). IEEE, Proquest, Web of Science, and Scopus were investigated. Here, Scopus allowed for a focused search and provided the most information related to the key concepts described in the Theoretical background. The database only consists of peer-reviewed papers, which enhanced the quality of this study. IEEE has a clear technological focus, where technical details regarding software and hardware were emphasized in the papers. Therefore, it is less relevant to include IEEE. Proquest and Web of Science were also considered, but it appeared that the vast majority overlapped, where new papers did not provide extra novel insights. Thus, Scopus is the

only source of data used due to information overload and the time boundaries of this study. Furthermore, the time of publication had to be set for obtaining recent information about a topic. The publication year 2011-2022 applies for this research, since the German government announced Industry 4.0 at the Hannover fair in 2011. This may be seen as the start of the industry 4.0 revolution (Madsen, 2019). Lastly, the subject area and search string had to be defined. These two criteria are subjected to the SLR executed. Therefore, these criteria are further elaborated in the respective SLR.

Search
The second step involved the actual search for literature, which is in constant iteration with the first step. The search strings were filled into the predefined databases, and restricted to the inclusion criteria that were defined on the forehand. This step involved constant iteration with the first step, extracting the ideal literature set. This iteration stopped whenever a valuable and sufficient amount of literature was reached.
Besides the sample derived from the define step, the research was complemented with second-hand research. Garousi et al. (2019) emphazised importance the so-called “grey literature”, also called second-tier data. These papers are often identified as more valuable than papers from theory within the subject of Industry 4.0 (Dikhanbayeva et al., 2020). Thus, grey literature is added to the initial dataset because it serves as an essential source of information due to the richness of practical research contributions of consulting and automation companies

Select
The outcome of previous step was a set of literature derived from a systematic search, complemented with practical research. However, not all research that is included in this set was suitable for this study. Therefore, the unstructured sample had to be refined to the requirements of this study. Hence, this research followed the main concepts for refining from Wolfswinkel et al. (2013), but slightly adjusted to the purpose of both SLRs. These steps are elaborated on in the corresponding SLR.

Analyze
The final sample extracted from the “Select” stage consists of a selection of papers that represent the most relevant data that can be found on this subject. However, the data was still unstructured and dispersed over multiple papers. Firstly, the papers were read carefully to get familiar with the data. After that, the papers were reread, and the key findings that could contribute to this study were noted down. The key findings were highlighted, coded, and summarized per paper. At this point, the results are author-centric and unsuitable for synthesizing. The transition had to be made to a concept-centric viewpoint for a complete overview of the data (Webster & Watson, 2002). A concept matrix is a valid method to do this, which served as a helpful tool for the researcher to create the final framework.

Present
A logical and structured construct had to be developed with the concepts derived in the previous step. Most of the choices of which concepts are used in the construct were made objectively, and some were subjectively made. These choices count on logical reasoning and cognitive pattern recognition from the researcher. Although, some choices also depend on the researcher's creativity (Wolfswinkel et al., 2013). For this reason, some choices appear to be more subjective and less understandable for the reader. Hence, a balance between objective and subjective reasoning has been sought, where clear reasoning supports the latter. Every SLR clearly described what choices were made to come to a final construct. Before deriving a construct, it is vital to understand in which way the data could be presented to the audience. A poorly presented research is most unlikely to be disseminated (Okoli & Schabram, 2010). This aligns with one of the key challenges identified in the Theoretical background, describing that OEMs struggle with understanding Industry 4.0, which is vaguely described in theory. This emphasized the need for a visualization of the construct by means of an overarching framework that integrated the individual results of both SLRs and empirical research. Namely, visual representations enhance faster assessment of the data and better framing of the outcome (Alencar et al., 2012).

The next Chapter describes how SLR 1 and, subsequently SLR 2 were executed. It elaborated on the choices that were made during the process.

5. Systematic Literature Review 1 (SLR1)

5.1. Define

In the first step, the search criteria were defined. The previous section elaborated on the inclusion criteria that apply to both SLRs. However, two search criteria differed between the SLRs: subject area and the search string.

First, the subject area had to fit the area of interest for this particular SLR. The main focus of this research is more business-oriented. However, the subject of this research is Industry 4.0, which lies in the IS (Information Systems) domain. This research focuses on technological and operation-oriented MMs, which means that it had added value to add technical subject areas in this SLR. Hence, all the subjects related to manufacturing, IT, and business are selected from the search databases. These domains were identified as the most frequently used domains in Industry 4.0. Other domains that focus on a niche subject were excluded from the SLR in the first place. Examples of niche subjects are Mathematics, Energy, Social Sciences, and Chemical Engineering. MMs in these domains may be relevant but are not a priority in the first place.
Although this research focuses mainly on business, Manufacturing and IT were also chosen for this SLR. That is because the MM that is constructed for this research should have technological or process-oriented aspects in each phase. That is, it is important that the phases in the MM were built on a specific technology or operation, and not on capabilities, for example. It is more likely that VCA concepts are built on key aspects such as “condition monitoring” and “AI”, in contrast to key aspects such as “leadership style”, which were frequently mentioned in CMMI. For example, pay-per-use business models are enabled if the output of a machine is known, which could indicate data logging. Contrastingly, no VCR and VCA concepts can be found if “the organization is able to recognize Industry 4.0” as a key aspect of a MM phase.

Second, two search strings were defined that represent the focus of this SLR. The search string can be divided into three parts that serve a specific purpose: The area of interest, the subject area, and the specialization.

The *area of interest* in this SLR is "maturity model". Similar terms such as "readiness model", “CMMI”, and "assessment model" were excluded from this study, as they focus more on organizational capabilities. Hence, these kinds of models are unsuitable to serve as a basis for VCA concepts. Whereas maturity models focus on a roadmap, do these models provide a snapshot of the current state of the OEM based on multiple aspects. The term “roadmap” was also excluded since it serves a broad definition, used for multiple purposes.

The second part of the search string defined the *subject area* of this SLR. As described before, this research focuses on Industry 4.0, IoT, and other variants.

The last part of the search string relates to the *specialization* of the SLR. In this case, the Industry 4.0 maturity model had to apply to the TCP of IXON Cloud. However, SME specialization is not included in the search string, since research on this topic is limited. Also, MM that are specified to SMEs were not As a consequence, MM phase descriptions were sparse and not sufficient for further research. Thus, this SLR focuses on OEMs in general in the first place. Nevertheless, the keyword “OEM” is not included in the search string because limited research uses OEM as a name for machine builders. Though, including this only limits the dataset. Therefore, the keywords Manufacturing and Machining were used to specify this research to the manufacturing industry or more specifically, machines. These Specialization keywords represented this research’s goals best.

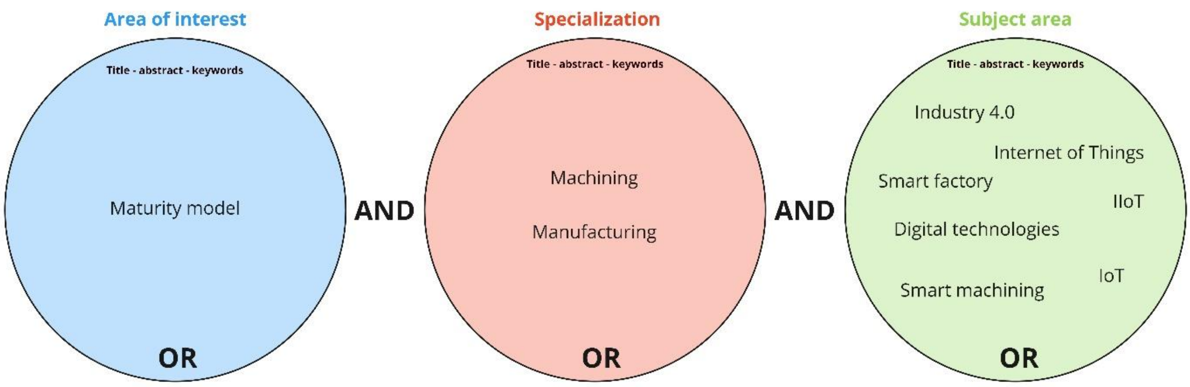


Figure 3: Schematic overview of the search string in SLR 1

Figure 7 shows a schematic overview of the search string, divided into smaller segments. Table 1 shows an overview of the final set of search criteria defined for this SLR.

Table 1: Predefined search criteria for SLR 1

Predefined search criteria for SLR 1	
Database	Scopus
Publication year	2011-2022
Subject area*	Business, Management, and Accounting - Computer Science – Engineering – Decision Sciences
Document type	Conference paper - Article - Review - Conference review
Language	English - German – Dutch
Search string*	TITLE ABS KEY (("Maturity model*") AND ("Industry 4.0" OR iiot OR iot OR "Internet of Things" OR "Smart machin*" OR "Digital technolog*" OR "Smart factor*") AND (manufacturing OR machin*))

* = inclusion criteria differ between SLRs

5.2. Search

This step involved the actual search for literature. It was a highly iterative process, constantly revising the search criteria defined on forehand. This resulted in a set of literature derived from the search criteria that was complemented with grey literature. Appendix 1 contains a selection of grey literature suitable for this SLR. The table describes the title, authors and/or institution, and also the background of the publisher. It is vital to know the background of publishers to understand their interests and intentions. Knowing the background of the publisher is a requirement for inclusion since it may indicate validity and reliability of the paper (Garousi et al., 2019).

Table 2 shows the amount of papers found in both concepts. It presents the first selection of literature that forms the basis for the next step in this SLR.

Table 2: First paper selection of SLR1

First selection of papers in SLR1	
Source	**# amount of papers**
Search query	132
Grey literature	8
Total	*140*

5.3. Select

The first selection of this SLR count 140 papers. However, the papers that were included from the search query may not suit this research. Therefore, two selection rounds were executed to filter the papers to reach a final sample that represents the theory about this topic.

First selection round

In the first step in Figure 8, the sample should be refined based on the abstract. However, this step is slightly different for SLR 1. That is because the abstracts of the papers on this subject did not provide enough information for the inclusion or exclusion of a MM. Therefore, the first selection was not refined on the abstract, but on the content of the paper. More specifically, it involved a screening of the MM that was present. Usually, this task step is time-consuming and mostly not feasible in a research's scope. Though, most of the papers in this SLR visualized their MM. That enables a fast and easy assessment of the content. Therefore, the first selection consisting of 141 papers was refined based on the MM itself.

The assessment of the MM was based on assessment criteria. Every paper was assessed on five predefined criteria to keep the most relevant MMs in the SLR. Each criterion represents an aspect that determines if the MM suits this research or not. Most of the criteria were based on a 3 -or 5-point Likert scale, depending on its importance. All these scores were added up, representing the final score. The final score had to be higher than the threshold for inclusion in the second selection. The criteria are as follows:

I. *First check (FC)*: Before the other criteria were assessed, the paper was checked if the overall content of a paper is useful for this study. This criterion comprises the first pass check, which can be answered with yes or no. If answered no, the paper will be dismissed without assessment of the other criteria below. A reason for this could be that there is simply no MM present or the paper described a readiness model. The last box implies additional information on what reason the paper is rejected for further investigation. When answered yes, the study is assessed on the other criteria stated below.

II. *Applicability (A)*: This criterion assesses if the MM is applicable for this study. This is a partly subjective, and partly objective criterion determined by the researcher. The researcher determined whether the MM model explained the full industry 4.0 revolution well or either a part of it. In addition, it assessed if the MM describes the right purposes for this study, smart machining. A reason for low applicability can be that it did not focus on smart machining, but IIoT is used for internal organizational processes.

III. *Target (T)*: This criterion assesses whether the paper is targeting the TCP of IXON Cloud, providing a better fit to the empirical study later this research.

IV. Detail (D): This criterion assesses if the stages in the MM are described with extensive and well-defined argumentation. For example, this criterion scored low when a MM phase is described with one or two words.

V. *Orientation (O)*: This criterion assesses if the phases in the MM focus on a technological or process-oriented aspect of Industry 4.0. A reason for a low score can be that a paper describes environmental aspects as the key indicators. For example; phase 1 = factory reduced 20% emissions with Industry 4.0; phase 2 = factory reduced 40% emissions with Industry 4.0. A MM with this description could not be linked to VCA and are therefore not usable for this study.

How the scaling of the criteria was defined and what the scores indicate are explained in detail in Appendix 2. The table in Appendix 3 shows all the papers of the first selection.

Second selection round

The first selection round assessed the papers on the MM that were described textually or visually, instead of an assessment based on the title, abstract, and keywords. As all the relevant information of the paper is already summarized in the MM itself, the review of the first selection round is sufficient to get a deeper insight into the paper. Therefore, a second selection based on the full text is no longer required. Hence, the second selection resulted in an identical sample as the third selection.

After that, the papers retrieved from snowballing was applied to the third selection to find relevant research from outside the dataset. Here, 3 additional papers derived from snowballing were added to the third selection, making the fourth selection. The papers that were retrieved from snowballing were indicated with a star (*) in table 3.

Third selection round

Although the papers in the dataset were peer-reviewed, an additional quality check is executed to retain a high standard. Each paper in the fourth selection composed in the previous step was assessed on at least one quality criteria. Since not all papers could be assessed with one overarching quality criteria, three criteria are used: Scopus Paper Quartile, CiteScore and JIF. Further explanation of the quality criteria can be seen in appendix 5. How each of the papers was rated is also shown in appendix 5.

All papers that can be ranked individually scored high on the Scopus Paper Quartile Metric, except for one medium-ranked paper. Most papers that could not be ranked individually scored at least medium on CiteScore and JIF impact concepts. Only paper 121 scored low on the CiteScore ranking, which was still above the threshold. However, an additional investigation is done to assess the added value of this low-scoring study. It appeared that the MM in the paper provided clear phases with technology as the key concept. Therefore, it was decided to still include the paper in the final selection.

After two selection rounds, 20 papers were included in the final selection sample of SLR 1. These 20 papers can are listed in table 3 below with a short analysis of the MM in the paper. The table provides an overview of which papers were selected, what the paper scored in the first selection round, which maturity phases were described, and what the key characteristics of the MM are. Figure 8 shows a schematic overview of the entire selecting process.

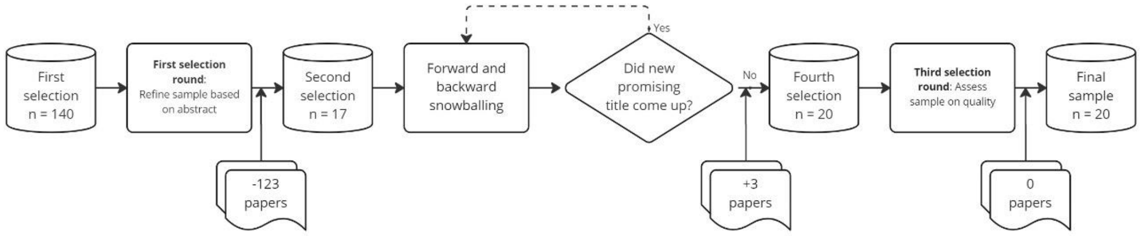


Figure 4: Workflow of selection procedure in SLR 1

Table 3: Final selection of papers in SLR1

Nr.	Title	Author(s)	Date	Tot
142	Industry 4.0 Maturity Index	ACATECH; Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W.	2020	17
145	Industry 4.0: Building the digital enterprise	Pwc; PricewaterhouseCoopers	2016	16
148	Smart Machine Maturity Model	Rockwell automation	2021	16
4	Smart Factory Implementation and Process Innovation	David R. Sjödin, Vinit Parida, Markus Leksell, and Aleksandar Petrovic	2018	16
147	Industrie 4.0 quo vadis?	Fraunhofer ISI	2020	15
6	Development of an assessment model for industry 4.0: Industry 4.0-MM	Gökalp, E., Şener, U., Eren, P.E.	2017	15
152*	SIMMI 4.0 - A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0	Leyh, C., Bley, K., Schäffer, T., & Forstenhäusler, S.	2016	-
149	Guideline Retrofit for Industrie 4.0	VDMA; Anderl, R., Picard, A., Wang, Y., Fleischer, J., Dosch, S., Klee, B., & Bauer, J.	2021	15
150*	Maturity Model for Data Driven Manufacturing (M2DDM)	Weber, C., Königsberger, J., Kassner, L., & Mitschang, B.	2017	-
21	To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises	Lin, T.-C., Wang, K.J., Sheng, M.L.	2020	14
32	The IoT technological maturity assessment scorecard: A case study of norwegian manufacturing companies	Jæger, B., Halse, L.L.	2017	14
65	An effective architecture of digital twin system to support human decision making and AI-driven autonomy	Mostafa, F., Tao, L., Yu, W.	2021	14
144	The Connected Enterprise Maturity Model	Rockwell Automation	2014	14
11	Contextualizing the outcome of a maturity assessment for Industry 4.0	Colli, M., Madsen, O., Berger, U., Wæhrens, B.V., Bockholt, M.	2018	13
51	A method towards smart manufacturing capabilities and performance measurement	Xia, Q., Jiang, C., Yang, C., Shuai, Y., Yuan, S.	2019	13
85	Design of a business readiness model to realise a green industry 4.0 company	Benešová, A., Basl, J., Tupa, J., Steiner, F.	2021	13
121	Review of research issues and challenges of maturity models concerning industry 4.0	Vijaya Kumar, N., Karadgi, S., Kotturshettar, B.B.	2020	13
151*	A Smartness Assessment Framework for Smart Factories Using Analytic Network Process	Lee, J., Jun, S., Chang, T. W., & Park, J.	2017	-
9	A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management	Caiado, R.G.G., Scavarda, L.F., Gavião, L.O., Nascimento, D.L.D.M., Garza-Reyes, J.A.	2021	12
58	A Developed Analysis Models for Industry 4.0 toward Smart Power Plant System Process	Indrawan, H., Cahyo, N., Simaremare, A., Paryanto, P., Munyensanga, P.	2019	12

*= Retrireved by snowballing method

5.4. Analyze

5.4.1. MM

The next step was to examine the papers chosen from the final sample. Again, the papers were carefully read to determine which phases were described in each. The MM phases and a short description of each paper were summarized in the table in Appendix 7. As can be seen in this table, every paper has its own road towards Industry 4.0 maturity and naming of phases. Thus, the names of these phases often do not match but describe entirely or partly the exact key characteristics. A critical step in the analysis process is to analyze these phases and find commonalities between them. These MM phases were categorized and listed under an overarching name based on the key characteristics. The key aspects could be identified in terms of technology, process and people. For this study, technology and process are key aspects for categorizing a particular phase. These overarching names, named concepts, are depicted in a concept matrix to get an overview of the concepts mentioned in each paper. The concept matrix can be seen in table 3.

These overarching concepts were listed on the x-axis, and the corresponding papers that mention these concepts are listed on the y-axis. The matrix also shows that one paper in the final sample has targeted the MM to SMEs. First, phases with unique key characteristics were listed down the table under a new concept name. Whenever a phase arose that described the same key characteristics as another, it was categorized under the corresponding concept it fit. In the case a new phase appeared that had no commonalities with earlier identified concepts, a new concept was derived. These steps were executed for every paper until all the phases in the final sample were described.

A selection of all these concepts is made to develop a final MM that could serve as a basis for VCR and VCA purposes. These concepts were chosen based on the frequency and subjective reasoning of the researcher. The second-last row in the concept matrix describes how frequently each phase appeared in the final sample. Frequency is an essential indicator of the importance of a concept in Industry 4.0 MM. This ensured that the most important concepts were included and the less relevant ones were excluded or either combined with other concepts. The latter was the case whenever a MM phase overlapped with other phases. That is, it appeared that multiple concepts were described individually, and in some papers, these were combined into one overarching paper. For example, in three papers were the characteristics of the concept “Standardization” mentioned together with the characteristics in the concept “Exploring”. The last row in the table shows the maximum number of times a concept is described together with one other concept in the matrix. This number indicates how frequently an original concept is mentioned alongside another concept. If a concept appeared at least half the time in another one, it was incorporated into the more frequently mentioned concept.

Table 4: Concept matrix for SLR 1

		Concept matrix for SLR 1																				
		Target		Concepts																		
		All OEMs	SMEs	Zero digitalization	Computerizing	Assessing	Initiating	Lacking	Connecting	Standardization	Checking	Collecting	Exploring	Changing BMs	ERP integration	Understanding	Decision making	Predicting	Integrating	Simulating	Automating	Automating VC
final selection	142	x			x				x		x		x		x	x		x			x	
	145	x			x				x					x				x	x		x	
	148	x			x				x							x		x		x	x	
	4	x							x				x			x		x	x		x	
	147	x			x								x			x		x				
	6	x		x	x		x	x		x			x	x	x	x		x			x	
	152	x			x		x						x	x		x		x	x			x
	149		x								x		x			x		x			x	
	150	x		x	x			x			x		x	x						x	x	
	21	x			x		x	x	x	x			x					x	x		x	
	32	x			x				x	x			x			x		x	x		x	
	65	x														x		x		x	x	
	144	x				x			x							x		x				
	11	x		x	x							x	x			x	x				x	x
	51	x		x	x							x	x		x	x		x	x	x		
	85	x		x	x							x	x		x	x			x	x	x	
	121	x		x	x							x	x			x	x					
	151	x									x					x		x			x	
	9	x			x		x	x		x		x	x			x		x	x		x	
	58	x		x	x			x								x		x	x		x	
Total		19	1	7	15	1	4	5	7	5	3	6	14	4	4	16	2	16	9	5	15	2
Overlap				1	1	0	0	1	2	2	2	3	3	1	3	3	0	3	4	2	3	0

All the concepts in the concept matrix are valid steps OEMs could face toward Industry 4.0 maturity. However, not all aspects are evenly important and necessary to consider. Thus, the initial MM should consider at least the required steps that SMEs have to complete and the steps from which business can be derived.

As can be observed in the table, five concepts appeared that were mentioned in the majority of the papers in the dataset. The concepts Computerizing, Exploring, Understanding, Predicting, and Automating were mentioned at least 14 times out of 20 times. This finding indicates that these concepts form the basis of Industry 4.0 and can not be neglected in the initial MM. Diving deeper into the concepts, it appeared that Computerizing is not part of the actual Industry 4.0 transition but named as a requirement for it. Appropriately, this phase is included as a stepping stone towards Industry 4.0. Exploring, Understanding phases were considered the core of the Industry 4.0 transition, involving data collection and monitoring. Although Exploring and Understanding both describe data monitoring, scholars clearly distinguish between these two concepts. As the Exploring phase only accounts for monitoring quality data for information purposes, the Understanding phase requires other knowledge and skills to improve maintenance and operations. For this reason, these two are both individually and subsequently included in the initial MM. Understanding and Predicting are both highest mentioned, indicating the importance for smart machining. These two phases are mainly accountable for the improvements made in maintenance and operations. 14 scholars concluded the MM with the Automating phase, whereas only one paper mentioned a phase coming after the Automating phase. Thus, Automating is considered to be the end-point of the MM.
At this point, there is no starting point before OEMs should computerize. As described earlier, most OEMs have not started the Industry 4.0 transition, indicating that there is no digitalization or some digitalization in the company. Especially SMEs could identify themselves in this phase, not possessing the right digital resources before starting Industry 4.0. This phase is mentioned 7 times, which is above average in the concept matrix. Even though, in all these cases, it is followed by Computerizing. This finding indicates that it can serve as a starting point toward Computerizing. Holding into account that this research is adjusted to SMEs later in this study, the No digitalization phase is also included. It is more pronounced an SME is not digitalized yet, rather than an OEM in general.
Another concept that is mentioned 7 times is the Connecting phase. This phase is mentioned chiefly by grey literature, indicating its importance in practice. Most of these papers describe this phase under the exact name

Connection, which suggests that research agrees about the concept. Just as the Computerizing phase, this phase serves as a requirement for Industry 4.0, specifically required for data practices. This phase ensures the IT/OT environment is connected for data exchange. Next to that, Schuh et al., 2020 described that OEMs can perform remote assistance to the end-user, pointing toward new business model development. As this phase is mentioned frequently and consistently and serves as a way to derive business, it is included in the initial MM.
Lastly, the concept "Simulating" was considered to be included in the MM, despite being mentioned only five times. This concept comprises the visual and dynamic representation of machines that make it able to simulate past and future events. This phenomenon is called the Digital Twin. According to Weber et al. (2017), the Digital Twin was still underdeveloped back in 2017. One other paper from 2019 and three from 2021 described this concept. This means that three of the five papers published in the last two years mentioned this concept in their MM. Therefore, excluding this concept based on frequency is not viable as it has been a hot topic over the last two years and may be in future research. As a result, research on this topic is still sparse and does not represent the importance of this concept yet. Also, this concept has a clear key concept Digital Twin, whereas it is evident that business can be derived in this phase. Therefore, this concept was added to the other eight concepts.
The remaining concepts in the matrix were mentioned less than 7 times. After an assessment of the content of these concepts appeared that these were either unsuitable to serve as a basis for VCR and VCA factors, or either not essential to include in the initial MM.

The concepts that apply to this norm were colored green in the second-last row of the concept matrix. The last row
As described before, whenever a concept is mentioned more than half in another concept, these are combined with the concepts they are mentioned in. The concepts that were initially excluded were considered to be viable for OEMs based on the current MM phases. Here, "Collecting" was mentioned six times, one time below the threshold. However, the last row shows that this concept was half the time mentioned along with "Exploring". Hence, data collection and sharing (vertical integration) are mostly mentioned together. Descriptions such as "data is collected and shared according to value stream needs" and "structured data gathering and sharing to facilitate data management practices" support this reasoning (Colli et al., 2018; D. R. Sjödin et al., 2018). Therefore, these two concepts were combined into the "Exploring" concept. The same counts for the concepts "Checking" and "ERP integration" which were mentioned more than half of the time together with the "Exploring" concept. Again, these two were also added to that concept. Other concepts were also considered, but not included due to its unimportance and overload of phases.

In conclusion, the initial MM consists of nine phases: No digitalization, Computerizing, Connecting, Exploring, Understanding, Predicting, Integrating, Simulating, and Automating.
This initial MM consists of a large set of phases compared to other MMs in the sample. Its extensive character is grounded in the importance of understandability. As the final framework targets SMEs, this MM must describe the steps extensively. As described, SMEs do not have the skills and resources to take multiple steps simultaneously. The MM requires smaller steps in time to make it manageable for SMEs. Even though, almost all steps besides Computerizing in the initial MM have the potential to derive business. It makes it comprehensible for them to identify business opportunities in each of these smaller steps.

5.4.2. VCR

As described in the research design, this SLR also accounts for the extraction of VCR factors within each of the MM phases found in theory. From the final selection, 16 of the 20 papers described how value can be created for at least one of the final MM phases that were included. The findings are listed down in a table with the corresponding number of the paper. These were complemented with the findings from SLR 2. The combined table can be seen in Appendix 6.

5.5. Present (Maturity Model)

These nine concepts represent certain stages in the initial MM. Figure 9 shows the phases visualized and with keywords of what the phase entails. The complete definition of each phase is described below. SLR 1 now answered the first research question (RQ1): “What does the current Industry 4.0 MM for OEMs look like that can serve as a basis for VCR and VCA concepts?”. This MM formed the basis to execute the next SLR.

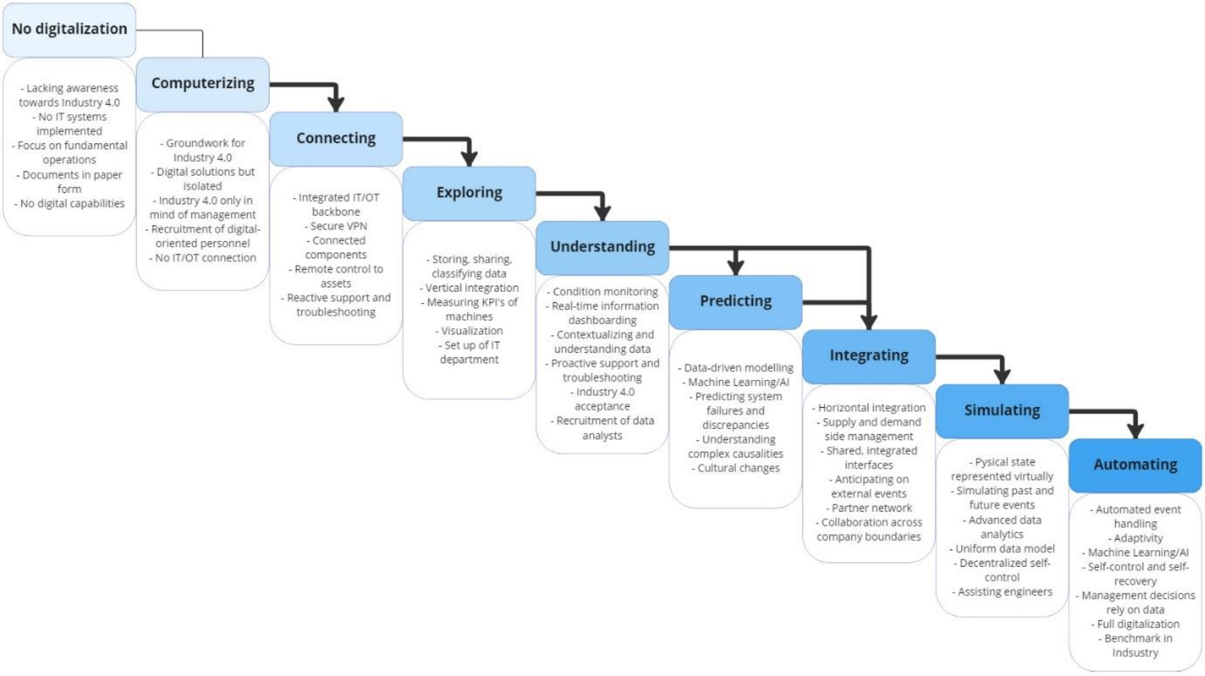


Figure 5: Initial MM

5.5.1. No digitalization

In the first stage, the OEM is at the very start of the industry 4.0 revolution. There are no industry 4.0 technologies implemented yet (Gökalp et al., 2017). In fact, it lacks digital awareness in the company, and the organization does not even have an idea or plan for industry 4.0 (Colli et al., 2018) (Benešová et al., 2021). The organization focuses on fundamental operations such as sales, production, and acquisition (Gökalp et al., 2017). That means the organization does not use management systems like ERP or PDM (Benešová et al., 2021) (Xia et al., 2019). Therefore, all documents are prepared, stored in paper form, and distributed manually (Colli et al., 2018). Hence, no data is collected (Xia et al., 2019). That makes the production planning and management dependent on human resources, and there is no consciousness of the processes in the company (Vijaya Kumar et al., 2020) (Xia et al., 2019).

Without an appropriate management system, it makes it harder for engineers to detect errors and find solutions quickly. The engineer has to recapture lots of data to improve the machine, which makes quick identification and improvements on the machine impossible (Weber et al., 2017). On the other hand, the company uses digital design systems like CAD in R&D and engineering to design the machine. An disadvantage here is that the drawings have to be exported manually since there is no integration with IT. The exact applies to the machine since it does not have a digital interface or integration with IT (Weber et al., 2017). In addition, there are no capabilities and technologies available for developing an infrastructure suitable for employing industry 4.0.

For the next step in the maturity model, the company require a digital foundation to collect relevant data. The production manager and relevant co-workers have to get together to organize data requirements. After that, it is necessary to digitalize its company's processes and retrofit its machines.

5.5.2. Computerizing

The second stage comprises the computerization of the company's processes and products. Computerization is required as the groundwork for the further industry 4.0 roadmap.
Here, the first digital solutions are applied, but isolated (PWC, 2016). The companies in this stage are not yet service-oriented or able to implement cloud-based applications since the company is not yet able to build an infrastructure suitable for implementing industry 4.0 technologies (Caiado et al., 2021) (Leyh et al., 2016). Therefore, no guarantee is given that the data is protected from cyberattacks and espionage (Leyh et al., 2016). The company focuses on efficient processes for every department (Schuh et al., 2020). Hence, the process is still reactive and based on experience and informal decisions, which makes the process poorly controlled and unpredictable (Caiado et al., 2021) (Indrawan et al., 2019).
That is because the industry 4.0 revolution is only in management's mind, communicated to employees via channels to keep them aware of updates so that personnel stays familiar with the companies' strategy (Benešová et al., 2021) (Schuh et al., 2020). However, the recruitment of new people with industry 4.0 capabilities will start at this point, and existing personnel will be trained in process management (Benešová et al., 2021).
Digitalization is also applied to perform tasks more efficiently (Schuh et al., 2020). On the IT side, management information systems such as ERP and PDM are applied for the critical processes in the company (Xia et al., 2019). These are necessary to collect and store relevant data for all the key business activities in the company, which is a requirement in later stages. ERP is implemented in this stage since it is the foundation for every manufacturing company by collecting, interpreting, managing, and storing data from business activities (Xia et al., 2019) (Benešová et al., 2021). However, it is typical for this stage that the ERP levels are internal to the organization and in limited integration with other levels (Jæger & Halse, 2017). For later integration, companies also require a PDM system. PDM is used to manage the technical documents, bill of material, and product designs (Xia et al., 2019). These systems can be used later in the process to integrate and align with industry 4.0 technologies and processes.
Conclusively, the company is at the start of the industry 4.0 revolution. The digital foundation have been laid, but there is yet no connectivity and communication between IT and OT. The next step is enable data flow between these systems and machinery.

5.5.3. Connecting

The third stage comprises the understanding of technical requirements necessary to create the groundwork for a smart factory (D. R. Sjödin et al., 2018). It involves the connection of assets in the company to enable data flow, required in later stages. At this point, companies often rely on outdated networks and controls around the machine, which are inappropriate for data collection with IoT (Jæger & Halse, 2017; D. R. Sjödin et al., 2018). Therefore, the company has to build an OT/IT infrastructure where isolated components from the Computerization stage will be replaced by connected components (Rockwell, 2014) (Schuh et al., 2020).
As a result, connectivity within a company enables automated digital tasks by forwarding data and documents through the company and assets with minimal manual involvement (Schuh et al., 2020).
Also, OEMs can now access and manage the machine anytime (Jæger & Halse, 2017) (Rockwell, 2021). That makes it possible to program the machinery remotely and manage machinery with a PC, tablet, or smartphone (Jæger & Halse, 2017). A next step is that a platform can be created that comprises all the company's connected components, such as machinery. One way of doing that is to involve external actors in platform development, such as end-users, suppliers, and contractors (D. R. Sjödin et al., 2018).

Consequently, components can be reached from outside the company, which causes significant challenges with security. Therefore, a secure VPN modem and a reliable IT/OT infrastructure are essential to secure the entire company and machines in the field from cyberattacks or espionage (Rockwell, 2014) (Rockwell, 2021). Hence, it is a prerequisite for companies to hire personnel with an understanding of both manufacturing and programming to bridge the gap between them (D. R. Sjödin et al., 2018). Also, new roles and responsibilities must be considered such as the responsibility for managing the new IT/OT infrastructure (Rockwell, 2014; D. R. Sjödin et al., 2018). Cross-functional teams are set up to manage the OT and IT infrastructure, develop the

industry 4.0 roadmap, and assess new technologies. However, these teams currently lack structure and consistency (PWC, 2016; D. R. Sjödin et al., 2018).
In this stage, there is a willingness to change in the company, but senior leadership will be responsible for removing obstacles when they are present (Schuh et al., 2020; D. R. Sjödin et al., 2018). It is vital to create a culture where personnel has the same vision towards industry 4.0 (D. R. Sjödin et al., 2018).
Nevertheless, in this stage, the project management will still be executed as it was before (Schuh et al., 2020). The process still relies on reactive actions and troubleshooting. The company still maintains the way of working by fixing the end user's problems and maintaining production (Rockwell, 2021). Although partial integration of IT and OT is reached, there is a focus on connecting more assets in the company and creating a standard dashboard for allowing data streams.
The assets of the company are now capable of communicating with each other. This allows data exchange between different assets and systems within the company. That makes it possible to monitor relevant parameters of the machine by capturing data from the PLC and added sensory, which will be used in next stages (Schuh et al., 2020).

5.5.4. Exploring

Now that the company has a stable and connected digital foundation, sensors are added to obtain valuable data about the machine (Schuh et al., 2020). In this stage, data is mainly used to monitor KPIs that are visualized on the dashboards created in the "Connecting" step (Schuh et al., 2020; Weber et al., 2017). That may give information about the OEE of the machine, such as production data and other key machine characteristics. Though, most companies have less or no experience handling these amounts of data. These companies commonly retrieve many irrelevant data that must be filtered (D. R. Sjödin et al., 2018). Data is also held in decentralized silos which are not connected to any other system (Schuh et al., 2020; Xia et al., 2019). Therefore, an essential activity in this stage is to manage all these data carefully by classifying, storing, and sharing the data with the help of business intelligence software. The classification and storage must be done systematically and in a well-defined database (Gökalp et al., 2017; Schuh et al., 2020). Nevertheless, data is only useful when it is shared with the people who can benefit from it. This is called vertical integration (Schuh et al., 2020).
Vertical integration makes it possible to share data from a production level to C-level (Garrocho et al., 2020). Still, most of the time, the data is only observed by the people with access and knowledge to retrieve the information (Schuh et al., 2020). That is because organizations should first shift their thinking and restructure their processes (Schuh et al., 2020; D. R. Sjödin et al., 2018). Companies have to set up standardized processes to share information across departments (Lin et al., 2020; D. R. Sjödin et al., 2018). Consequently, the organization has to assign employees who execute data insight coordinating tasks that act proactively in knowledge sharing. Hence, production employees will have adjusted roles, and must be trainedo access the data and gather knowledge-sharing capabilities (D. R. Sjödin et al., 2018).
Sensors, actuators and other data-related components should be integrated into the machine to facilitate vertical integration from a technological perspective (Gökalp et al., 2017; Schuh et al., 2020). Also, management information systems should communicate with each other and the database itself (Benešová et al., 2021; Lin et al., 2020; Schuh et al., 2020; Xia et al., 2019). This information can provide the bigger picture of the factory's status (Schuh et al., 2020). In addition, manufacturing data can be integrated with department-specific data and shared with after-sales, marketing, and logistics (Weber et al., 2017).
Optimal vertical integration is reached when KPIs are shared with the right people and with the right level of abstraction (D. R. Sjödin et al., 2018). Where the focus is currently still on hardware, software, and networks, this will shift to continuous improvement of the machine in the next stage (Rockwell, 2014).

5.5.5. Understanding

Transparency has been achieved now that valuable information reaches the right people in the company. However, information about only the OEE of the machine does not give a handhold for further improvements. Machine improvement can only be achieved if raw data is used for business insights and knowledge (Colli et al., 2018; Schuh et al., 2020). A crucial capability the company has to learn is understanding what is going on in the machine. With this understanding, it will be clear which data will be valuable to monitor (Rockwell, 2014).

When it is known which parameters are worthy of keeping track of, condition monitoring can be applied (Schuh et al., 2020). For example, wear and tear on the shafts occur when the motor current reaches a certain level. Condition monitoring is traditionally described as a technique or process where changes and trends can be observed by monitoring specified machine parameters performed by manual techniques, such as vibration measurement (Han & Song, 2003). Networked smart sensors make it now possible to visualize these changes in equipment and process data in real-time information dashboards, which were created in the "connecting" stage (Rockwell, 2021; Xia et al., 2019). The company's digital image is created based on collected data and integrated control systems (Benešová et al., 2021; Schuh et al., 2020). By contextualizing and analyzing these data, implications can be drawn(Colli et al., 2018; Rockwell, 2021; Vijaya Kumar et al., 2020). That will be the basis to benefit from the data to make smarter decisions in the future (Rockwell, 2021; D. R. Sjödin et al., 2018).

As in other stages, senior management is still responsible for cultural change in the organization for these technologies. Data analysts are recruited to optimize production since the focus is now on continuous development (Benešová et al., 2021; Rockwell, 2014; D. R. Sjödin et al., 2018). Compared to previous stages, employees now highly familiar with industry 4.0 and have an acceptance towards it (Xia et al., 2019). Hence, employees initiate further improvement towards industry 4.0, and departments such as design collaborate with production, sales, and supply chain to improve their processes (Schuh et al., 2020; Xia et al., 2019). That is because employees have seen the opportunities of the IT/OT network to recognize problems in real time (Rockwell, 2014). The IT department can now develop a customized information system and keep the IT infrastructure up-to-date (Xia et al., 2019).

Measuring the machine and anticipating on problems is the basis for a well-controlled factory. However, sometimes it is beneficial to predict whenever a problem is going to occur. Therefore, analyzing the data with advanced statistics can bring the company to an improved level of monitoring (Indrawan et al., 2019).

5.5.6. Predicting

If the complexity of problems increases, condition monitoring is often insufficient. Data-driven modeling or machine learning is more suitable for understanding complex causalities and predicting system failures (Benešová et al., 2021; Fraunhofer & VDMA, 2021). In the previous stage, condition monitoring could identify problems before they occur based on observation or limit values (Fraunhofer & VDMA, 2021). This stage extends condition monitoring by using advanced statistics to predict when these problems could occur in the future (Caiado et al., 2021; Fraunhofer & VDMA, 2021). A properly defined digital image from the previous stage is essential for this stage to succeed. This data defined and prepared is essential for this stage to work. That will lead to more accurate forecasting and better recommendations (Schuh et al., 2020).

Cultural change in the organization is essential to going one step further in the process. The organizational structure must be adjusted so that involved employees have decision-making rights and changes can be made rapidly when necessary (Schuh et al., 2020). Also, data scientists must be trained in predicting capabilities, which are required at this stage (Benešová et al., 2021). Openness to change and critical reflection are inherent to innovative technologies like these (Schuh et al., 2020).

Prediction can contribute to better asset management and production planning, which could be more beneficial if multiple actors and other external concepts can be integrated into the process (Colli et al., 2018; Rockwell, 2014). Hence, the next step involves the integration of actors across company borders.

5.5.7. Integrating

In the Exploring stage, vertical integration has been applied to align the processes between different departments. In this stage, the vision will be extended across company borders, which is called horizontal integration (Jæger & Halse, 2017; PWC, 2016). Horizontal integration can be defined as operability between a company and an external information network in the value chain for streamlined processes between companies to deliver better products and services (Lin et al., 2020; Zhou et al., 2016). Production and warehousing are highly automated, so the first step is made towards an automated factory (Jæger & Halse, 2017).

The basis for horizontal integration is a common IT architecture with shared and integrated interfaces (PWC, 2016). That means that partners from the supply and demand side can exchange real-time data between organizations in integrated data lake (PWC, 2016; Zhou et al., 2016). Even external events, such as business trends, weather patterns and market information can be used (Rockwell, 2014). All this information is used to develop an ecosystem where a company and its partners can anticipate on external events based on data (Rockwell, 2014). For example, decision-making in scheduling is automated, grounded on production state and customer orders (Colli et al., 2018). Big Data is first mentioned in this context because of the enormous amount of data Captured from different sources (Jæger & Halse, 2017).

Digitalization is a well-developed practice at all hierarchical levels in the company (Colli et al., 2018). Digital culture and encouragement of sharing data are key characteristics of this stage. Although, the risks of security and compliance are frequently addressed when sharing with partners (PWC, 2016).

Now that all data sources are added to an integrated system, the whole manufacturing ecosystem can be optimized (Lee et al., 2017). A big step has been made towards an automated factory.

5.5.8. Simulating

All aspects are now present to make a digital representation of the machine. This is called a Digital Twin (Mostafa et al., 2021; Rockwell, 2021). As the name suggests, it is a digital dynamic model of the physical asset in real-life (Mostafa et al., 2021). According to Weber et al. (2017), the Digital Twin was a new concept in the industry and was still under development in 2017. But in the last three years, it gained momentum with the rise of IoT (Mostafa et al., 2021).

Five capabilities are required for a OEM should possess when building a digital model of the machine. Data collection, data modeling, domain knowledge, analytics, and AI/ML are prerequisites for a fully integrated Digital Twin to work (Mostafa et al., 2021). Earlier stages in this roadmap are the groundwork for this technique. The company learns about collecting and preparing data in the Exploring stage, where the Understanding phase provides analytical skills and knowledge about all relevant machine parameters to be included. The Prediction phase lays the groundwork for machine learning or AI-based capabilities, which are required to predict future events (Mostafa et al., 2021). Integration on the input and output side is an addition for a more complete picture of the visualization. That may be useful when a Super Digital Twin is created. It combines multiple Digital Twins to visualize a production line or complete factory, which allows for higher levels of prediction, such as material and shipping management (Mostafa et al., 2021).

A digital model of a physical machine can help service engineers by diagnosing and troubleshooting when multiple states of the machine are known (Mostafa et al., 2021; Weber et al., 2017). It minimizes the amount of manual work since ML models are automated. Adding to that, it can retrieve crucial data patterns and advise service engineers with alarms, for example. Organizations are able to optimize the machine in the development phase by simulating several scenarios (Mostafa et al., 2021; Xia et al., 2019).

Management completely relies on this information, making decision-making more efficient (Weber et al., 2017; Xia et al., 2019). The organization turns out to be more service-oriented than production-oriented at this point (Xia et al., 2019).

In this phase, machines already start to be adaptive to a certain level (Xia et al., 2019). It will provide a basis for decentralized self-control of machines in the last stage (Weber et al., 2017).

5.5.9. Automating

Automation is the last step and even the endpoint of the industry 4.0 maturity model. The factory can completely operate by itself and control production without human intervention (Benešová et al., 2021; Lee et al., 2017). Here, real-time optimization and automated decision making is done by a self-learning algorithm in an intelligent database (PWC, 2016). The fundamental part lays in the Prediction stage, since AI and ML models are the basis for automated actions and decision making (Caiado et al., 2021; Schuh et al., 2020). The difference with the Prediction stage is that the these predictions are made automatically. AI models can detect abnormalities in certain events and recover these automatically (Lee et al., 2017). A feedback loop between machines and employees makes quick adaptivity possible (Schuh et al., 2020; Weber et al., 2017).

The focus is here on continuous improvement and adaptation to a changing business environment (Schuh et al., 2020). Employees have the right qualifications and share the same vision as management (Benešová et al., 2021). A characteristic of the Automation stage is that the digital model developed in previous stage behaves exactly as the physical machine (Benešová et al., 2021). End-to-end integration in an ecosystem for all business processes is reached, because of the strong collaboration with all partners achieved in the Integration stage (Colli et al., 2018; Leyh et al., 2016; PWC, 2016; Rockwell, 2021). As a result, business is evolved towards an innovative structure and new business models are created (Fraunhofer & VDMA, 2021; Gökalp et al., 2017; Rockwell, 2021). The company became benchmark in industry (Xia et al., 2019).

5.5.10. VCR

This SLR also contributed to the answer on the second research question: “How can OEMs create value for themselves and end-users in every phase of the Industry 4.0 roadmap?”. Therefore, the MM phases of each paper the final sample were investigated on possible ways for the OEM to create value for themselves and the end user. The added value of this method is that VCR was not described in general, but specifically for every phase included in the MM. The results are listed in a table, complemented with the VCR findings that were retrieved from SLR 2. The table with both outcomes can be seen in Appendix 6. The table consists of all VCR described per phase, with the corresponding paper number that described this.

6. Systematic Literature Review 2 (SLR 2)

6.1. Define

As explained in SLR 1, the inclusion criteria “subject area” and “search string” were different for both SLRs. First, the subject area “Business, Management, and Accounting” was applied for SLR 2. This differed from SLR 1, where the technical subject areas were also included. In this case, the topic VCA is purely grounded in business research with less overlap in technical-oriented research. Hence, excluding the technical subject areas limited VCA within technical research and maximized VCA from a business perspective.

Second, a search string was defined that represented the focus of this SLR. The search string can be divided into four main parts that serve a specific purpose: The area of interest, the subject area, the specialization, and the focus. The *area of interest* was targeted on concepts that describe how OEMs can use Industry 4.0 technologies for business opportunities. “VCA” and “Business models” are frequently used terms that account for this purpose. Similar terms such as monetization, incentivization, and revenue models were also considered. These three terms added six new papers to the search string defined, which were not providing extra value to this outcome of the SLR. As described before, current research mainly focuses on the Industry 4.0 revolution in general. Therefore, business cases are added to the search string for providing a practical view on how successful OEMs thrive business with Industry 4.0. “Use cases” and “best practices” that focus on value, benefits, and advantages serve the same purpose as business cases. These business cases serve as a tool to combine VCA with the corresponding MM phases.

The *subject area* also differs from the subject area in SLR 1. Here, two types of subject areas were defined. One part had a specific *focus* on VCA within each phase. Accordingly, the key aspects identified in each phase in SLR 1 are included. These are used to find VCA concepts that have a direct fit with a specific MM phases. To illustrate, one key aspect of the Predicting phase is called “predictive maintenance”, which is included as a subject area. The SLR provide ways of capturing value specifically for predictive maintenance, instead of Industry 4.0 in general. These VCA concepts can therefore be directly linked to the MM phase Predicting. The key aspects can be found in the MM in Figure 9 under the corresponding phase. Here, only the key aspects that could provide as a appropriate search words are included. This was based on the experience of the researcher and involved an iterative process. As a result inclusion of context-specific keywords enhanced the search for VCA concepts within the MM phases identified in SLR 1. In addition to the key aspects, the general terms “industry 4.0” and “digitalization” were used to broaden the scope of the subject area and search for VCA concepts for Industry 4.0 general. As described above, the business cases were used to combine these general VCA concepts with the MM phases derived in SLR 1.

The *specialization* was again limited to manufacturing and machining. Compared to SLR 1, an extra specialization was added with the advent of the specific focus on keywords for each phase. Therefore, “Industry 4.0” and “digitalization” was applied as a second specialization for the full text. This is used to prevent VCA concepts for the subject areas outside Industry 4.0. Namely, most of the keywords used in the subject area were not directly inclusive for Industry 4.0 purposes. For example, it prevented that VCA was described for vertical integration out of Industry 4.0 context. A visual overview of the search string as a whole can be seen in Figure 10.

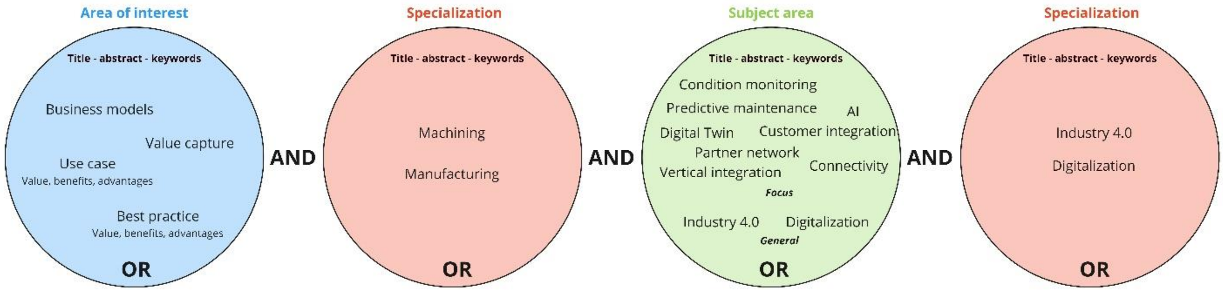


Figure 6: Visual overview of the search string for SLR 2

Table 5 shows an overview of the final set of inclusion criteria for SLR 2

Table 5: Predefined search criteria for SLR 2

Predefined search criteria for SLR 2	
Database	Scopus
Publication year	2011-2022
Subject area*	Business, Management, and Accounting
Document type	Conference papers - Articles - Reviews - Conference reviews
Language	English - German - Dutch
Search string*	TITLE-ABS-KEY (("value cap*" OR "business model*" OR "business case*" OR ("use-case*" AND value* OR advantage* OR benefit*) OR ("best-practice" AND value* OR advantage* OR benefit*)) AND (("industry 4.0" OR digitaliz*) OR (connectivity) OR ("vertical integration") OR ("condition monitoring") OR ("predictive maintenance") OR ("partner network" OR "customer integrat*") OR "digital twin" OR "AI") AND ALL ("industry 4.0" OR digitaliz*) AND TITLE-ABS-KEY ((machin* OR manufactur*))

* = inclusion criteria differ between SLRs

6.2. Search

This step involved the actual search for literature. It was again a constant iteration of the search criteria to obtain a manageable set of papers. In addition, three papers from grey literature were added to the first selection. The selection of grey literature can be seen in Appendix 1. The table describes the title, authors and/or institution, and also the background of the publisher. It is important to know the background of publishers to understand their interests and intentions. Knowing the background of the publisher is a requirement for inclusion since it may indicate the validity and reliability of the paper (Garousi et al., 2019).

Table 6 presents the overall statistics of the first selection that is formed with papers from the search query complemented with grey literature.

Table 6: First paper selection of SLR 2

First selection of papers in SLR 2	
Source	**# amount of papers**
Search query	253
Grey literature	3
Total	*256*

6.3. Select

The first selection of SLR 2 counts 256 papers. However, the papers that were included from the search query may not suit this research. Therefore, three selection rounds were executed by filtering the papers to reach a final sample that represents the theory about this topic.

First selection round

The first selection round of SLR 2 consisted of an analysis of the title, abstract, and keywords to filter the papers that were not applicable to this study. This assessment was argued based on five assessment criteria:

I. *First check (FC)*: This first check assesses if the overall content of the paper is useful for this study. This criterion comprises the first pass check, which can be answered with yes or no. If the answer was no, the paper was dismissed without assessment of other criteria. Reasons for rejection could be that there were no VCA techniques present or the paper has explicitly another subject as Industry 4.0. The last box implies additional information on what reason the paper was rejected for further investigation. When answered yes, the study is assessed on the other criteria listed below.

II. *Subject (S):* This criterion assessed what the role of VCA or similar terms were in the paper. Similar terms as VCA can be business models, monetization, revenue models, etcetera. This criterion scored high if the main subject of the paper was VCA within industry 4.0. This criterion could have scored low if VCA was a small part of a more prominent main subject.

III. *OEM-focused:* This criterion assesses how well the paper described VCA in a way that provides valuable information about how OEMs can capture value with Industry 4.0 technologies. This criterion scored high if VCA concepts or similar were described from an OEM viewpoint. For example, the paper describes that an up-time guarantee can be applied to a specific technology. This criterion scores low if it describes VCA for the end user. For example, the paper describes that the productivity of the machine increases, which generates additional products and money.

IV. *Target:* This criterion assessed whether the paper targeted the TCP, providing a better fit to the empirical study later in this research.

V. *Focus:* This criterion assesses if the paper has a focus on a specific MM phase identified in SLR 1. This criterion scored high if the paper describes VCA for a specific phase of the MM. For example, VCA concepts are explicitly described for predictive maintenance. This criterion scored low if the papers focused on VCA for industry 4.0 in general. For example, the paper describes that an SLA can be upgraded by implementing industry 4.0.

How the scaling of the criteria is defined and what the scores indicate is explained in detail in Appendix 2. The table in Appendix 3 shows all the papers of the first selection. It showed for every paper in the first selection if it passed the first check. If the paper met the requirements for further investigation, the paper was assessed by the other listed criteria. If not, the reason for the exclusion of the paper is shown in the last column. The papers that passed the first round check received a score for every criterion. The individual scores were added together, making the final score. The final score represents a number that shows how well the MM fits into this study. Similar to SLR 1, the papers that scored higher than 12 were included in the second selection. After the first selection round, 38 papers were left.

Second selection round

The title, abstract, and keywords gave an indication of the actual content of the paper. However, there is no guarantee that the paper provided the information that is valuable for this research. Therefore, a second selection round is executed by analysing the entire paper. This round was carried out to reduce the number of papers that made it through the first round. The second round of selection is depicted in Appendix 4. The papers from the second selection were listed in this table and evaluated based on their overall content. Following that, it was decided whether or not the paper should be included in this SLR. Sixteen publications were ruled inappropriate for this study. The 22 papers that came through the second selection round formed the third selection.

After that, snowballing was applied to the third selection to find relevant research from outside the dataset. Here, three additional papers were retrieved from snowballing and added to the third selection, making the fourth selection. The papers that were obtained with snowballing are indicated with a star (*) in table 7. These papers are found valuable as an addition to the existing base of literature in the third sample.

Third selection round

Each paper in the fourth selection composed in the previous step was assessed on at least one quality criterion. Since not all papers could be assessed with one overarching quality criteria, three criteria are used: Scopus Paper Quartile, CiteScore and JIF. Further explanation of the quality criteria can be seen in Appendix 5. How each of the papers was rated is also shown in Appendix 5.

All papers that could be ranked individually scored high on the Scopus Paper Quartile Metric, except for two medium-ranked papers. Most papers that could not be ranked individually scored at least medium on the CiteScore and JIF impact concepts. One of these papers that scored medium on the Scopus Paper Quartile was also published in a journal that scored below the threshold for inclusion. After a careful investigation, it was decided that the paper was excluded from the final sample. This decision is based on the fact that the paper did not have a significant contribution and decreased the quality of this study. There was no reason to exclude the other medium-ranked paper from the final sample.

After three selection rounds, 24 papers were included in the final selection of SLR 2. These papers are listed in table 7, with a short description of the content of each paper. Figure 11 shows a schematic overview of the entire selecting process of this chapter.

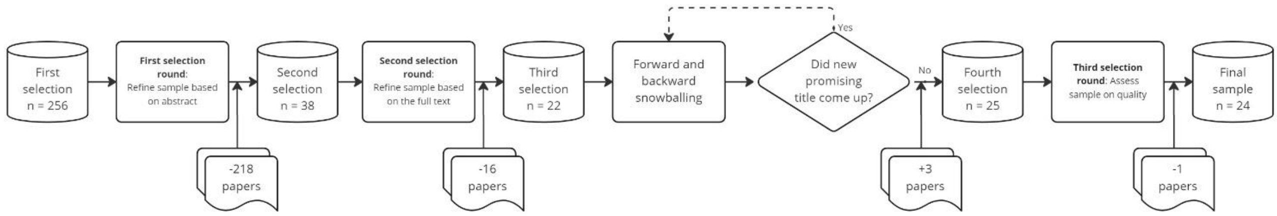


Figure 7: Workflow of the selection procedure in SLR 2

Table 7: Final selection of papers in SLR2

Nr.	Title	Author(s)/Institution	Date	Sc
180	How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	2022	14
381	AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	2022	14
407	Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	2020	14
153	Value capture in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	2022	13
159	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	2018	13
174	Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	2020	13
200	How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	2020	13
228	Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	2017	13
378	Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	2018	13
408	Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	2017	13
154	A data-driven business model framework for value capture in Industry 4.0	Schaefer D., Walker J., Flynn J.,	2017	12
158	Revenue Models for Digital Servitization: A value capture Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	2021	12
165	Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	2022	12
168	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	2021	12
173	Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	2019	12
184	Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	2018	12
187	Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	2022	12
321	An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	2020	12
352	After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	2022	12
406	Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	2020	12
142*	Industry 4.0 Maturity Index	Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W.	2020	-
409*	Time to listen to your machines	IBM	2016	-
410*	Predictive Maintenance: Beyond the hype	PwC	2018	-

*= Retrieved by snowballing method

6.4. Analyze

In this step, the 24 papers of the final sample were searched for VCR, VCA, and use cases to construct the initial framework. Although, this information was still unstructured and described in multiple papers. The papers in the final selection were read and summarized to overcome this problem. First, the papers were searched for VCA concepts. Here, irrelevant data was reduced, and only the useful information about the concepts was listed in a table. This step is vital for understanding the mechanism and reasoning behind a VCA concept, which is important for further analysis. The summary of the VCA concepts and their explanation can be seen in table 27 of Appendix 7. In addition, use cases were extracted and summarized to simplify and enhance the linking of a VCA concept to a specific MM phase, as described later in this section. This summary can be found in table 28 of Appendix 7.
The VCA concepts shown in table 27 are presented from an author-centric perspective. For analytical reasons, the findings have to be interpreted from a concept-centric standpoint. As a consequence, the findings are presented in an concept-centric manner in the concept matrix (table 8) below. Similar to SLR 1, the identified VCA concepts were listed on the x-axis, whereas the papers from the final selection were listed on the y-axis. The VCA concepts from Appendix 7 were filled in the concept matrix with the corresponding paper that mentioned it.

Table 8: Concept matrix for SLR 2

		Performance contracts					Subscription		Cost reduction			Output-based					Extra revenue				Pricing methods				
		Service level agreement (SLA)	Preventive maintenance contract	Prescriptive maintenance contract	Smart value contract	Customized contractual agreements	Subscription charged on a recurrent basis	Lease construction	Error reduction costs	Processing time reduction costs	Inventory cost reduction	Pay-per-use	Performance-based	Outcome-based	Based on the gain from sharing risk	Share of revenue increase	Higher product price	Additional services or upgrades	Consumables-as-a-service	Spare parts management	Pay-per-feature	Value-based pricing	Platform pricing	Product sale	Freemium
Final selection	180	x										e/u/p/s/a	e/u/p/s/a	x	x	x				p					
	381	n/p					p					p													
	407	x					x	x				x	x	x				s	x	p/u					
	153												x	x		x						x			
	159						x					x									x				
	174						p					x													
	200	x					x					e/u/p/s/a	e/u/p/s/a			x					x				e
	228						x					x					x								
	378								cn	p/u	x														
	408																			p					
	154						x					x	x					x				x		x	
	158											x	x									x			
	165												x					s							
	168		p	s		a				a			p												
	173											x									x				
	184						x							x											
	187	x											x	x	x	x		x					x		
	321							p							x										
	352	u					u						u	e/u/p/s/a											
	406				x										x	x									
	142	u																u/p							
	409								p																
	410								u																
	Score	**6**	**1**	**1**	**1**	**1**	**9**	**2**	**1**	**2**	**1**	**9**	**9**	**6**	**4**	**5**	**1**	**4**	**1**	**3**	**3**	**3**	**1**	**1**	**1**
	Total Indic.	**n/u/p**	**p**	**s**	**-**	**a**	**p/u**	**p**	**cn/p/u**	**p/u/a**		**e/u/p/s/a**	**e/u/p/s/a**	**e/u/p/s/a**	**-**	**-**	**-**	**u/p/s**		**p/u/**	**-**	**-**	**-**	**-**	**e**

Indicators: n=no digitalization, cp=computerizing, cn=connecting, e=exploring, u=understanding, p=predicting, i=integrating, s=simulating, a=automating

It appeared that the final selection of papers describes 24 ways of capturing value with Industry 4.0, as can be seen in the concept matrix. The different concepts were divided into six overarching categories in which value can be captured. These categories were derived from the paper's background information about the concept. With this information, the researcher could categorize a variety of VCA factors under a broader concept for a more straightforward assignment to the initial framework. The following categories applied for the findings: Performance contracts, subscriptions, cost reduction, output-based, extra revenue, and pricing methods. First, performance contracts are usual in manufacturing, where OEMs make agreements with the end-user about the performance of the machine. Secondly, subscriptions account for using a product or service based on a fee over a time period. Thirdly, cost reductions for OEMs are inherent to higher profits. Fourthly, monitoring the output enables output-based business models, where revenue can be generated for every increase in output. Fifthly, extra revenue can be generated by services enabled by Industry 4.0. Sixth, some papers described how Industry 4.0 integrated products and services could be priced. Lastly, two individual concepts could not be categorized.

For every individual VCA concept in the concept matrix can be seen how often it is mentioned and by which paper. Important here is that OEMs can identify in which way value can be captured in the MM phase they are currently participating. That means that the VCA concepts that be linked to a corresponding MM phase are prioritized. Every indicator represents a MM phase with its first (two) letter(s) of the corresponding phase. A black indicator means that the paper directly described VCA concepts for a specific phase in the MM, whereas a red indicator designates VCA concepts that were indirectly linked to a MM phase via use cases. Here, a cross mark simply indicates VCA concepts that can not be linked to a MM phase and describe its use for Industry 4.0 in general. The latter were not considered in the initial framework in the first place.

As a result, 14 original VCA concepts were found that can be assigned to one (or more) phases in the MM. Here, 5 concepts can only be used in a single phase in the MM. In contrast, 6 concepts can be used in two or three phases in the MM. As a result, these 11 concepts can be directly integrated to the corresponding phases in the initial framework.
Besides the VCA concept that were found explicitly within one phase, there are three VCA concepts that are frequently mentioned: Performance-based BMs (9), Pay-per-use BMs (9), and Outcome-based BMs (6). These VCA concepts are frequently mentioned because they are inextricably linked to Industry 4.0. In this case, VCA concepts are only enabled if the OEM is able to monitor the OEE of the machine. That is, these can only be used from the Exploring phase to the automating phase (e/u/p/s/a). Additionally, these VCA concepts are included in the final framework for the entire Industry 4.0 transition. The exact use of these concepts is further elaborated upon in the next section.
From the concept matrix appeared which of the VCA concepts could be applied to a specific phase in the MM. For inclusion of the concepts into the framework, it is helpful that the concepts and MM phases are converted. Here, the concepts were transformed to another viewpoint so that for every MM phase is known which VCA concepts were used. First, the VCA concepts within a MM phase are assigned. Thus, it could be noticed that the following VCA concepts occur in each of the following MM phases:

I. No digitalization: SLA
II. Connecting: error reduction costs
III. Exploring: freemium models, (performance-based BMs, pay-per-use BMs, and outcome-based BMs)
IV. Understanding: better SLAs, spare part management, subscription on a recurrent basis, processing time reduction costs, error reduction costs, additional services or upgrades, (performance-based BMs, pay-per-use BMs, and outcome-based BMs)
V. Predicting: better SLAs, subscription on a recurrent basis, error reduction costs, processing time reduction costs, preventive maintenance contracts, spare part management, leasing contracts, (performance-based BMs, pay-per-use BMs, and outcome-based BMs).
VI. Simulating: prescriptive maintenance contracts, additional services or upgrades, (performance-based BMs, pay-per-use BMs, and outcome-based BMs).
VII. Automating: processing time reduction costs, customized contractual agreements, (performance-based BMs, pay-per-use BMs, and outcome-based BMs)

6.4.1. VCR

An additional finding from SLR 2 are the VCR concepts that were described for a specific phase in the MM. In this SLR, 8 of the 24 described how OEMs could create value within each of the phases in the initial MM. These factors complemented the table with the VCR concepts found in SLR 1. This table consists of VCR factors and additional information to support the VCR concepts in a phase. This table can be seen in Appendix 6. Thereafter, the VCR concepts were summarized from this table and listed down in the concept matrix below table 9. Just as the VCA concepts, every VCR concept that is mentioned at least one time is included in the initial framework. It can be observed that the majority of concepts are described only once, indicating the sparsity of theory described per MM phase. However, the VCR concepts already show a good fit to this study, because these VCR concepts are directly derived from the MM phases. The reason for including all the concepts is that the framework is extensive and requires high input. As described earlier this section, a downside of this approach is that the theoretical validity decreases. Given the fact that the VCR concepts will be tested later in this study, overall validity enhanced thus far.

Table 9: Concept matrix with VCR factors from SLR 1 and SLR 2

	Papers from SLR 1 and SLR 2																										
	SLR 1	142	145	148	4	147	6	152	149	150	65	144	51	85	151	9	58	SLR 2	407	408	154	168	174	390	409	410	**Score**
No digitalization																											
Unstructured logistic processes																X											**1**
Spare parts fully used																				X							**1**
High downtime																				X							**1**
Damaged asset																				X							**1**
Minimized downtime																				X							**1**
Excessive maintenance																				X							**1**
Waste in spare parts																				X							**1**
Connecting																											
Faster support		X																									**1**
Strengthened relationship between OEM and service provider		X																									**1**
More secure network				X																							**1**
Exploring																											
Higher transparancy on OEE		X							X																		**2**
Quicker and better delivery data prediction		X																									**1**
Better production planning		X																			X						**2**
Improved utilization of machines																					X						**1**
Faster throughput times																					X						**1**
Higher customer satisfaction		X																									**1**
Understanding																											
Up to 70% reduced breakdowns																			X						X		**2**
Up to 50% reduced downtime																									X		**1**
Up to 50% reduced unplanned outages																									X		**1**
Up to 25% reduced maintenance costs				X	X	X																			X		**4**
Up to 12% reduced scheduled repairs																									X		**1**
Reduced maintenance hours from 50% to 70%																									X		**1**
Improved operational performance			X		X								X														**3**
Increased productivity																			X								**1**
Increased product quality					X																						**1**
Increased efficiency		X																									**1**
Preventing waste material					X																						**1**
Predicting																											
+9% to 20% uptime by optimizing repair and maintenance schedules			X																	X						X	**3**
+20% to 50% reduced efforts in maintenance planning												X															**1**
5% to 12% reduced maintenance costs																				X							**1**
From 4% to 5% productivity							X					X															**2**
-50% rejected products					X							X															**2**
5% to 12% cost reductions in operations and material expenditures																				X			X			X	**3**
36% energy savings																										X	**1**
-14% safety, environment, health and quality risks																										X	**1**
20% lifetime extension of machine																										X	**1**
Reduced inventory levels from 120 to 82 days												X															**1**
50% reduced lead times												X															**1**
80% to 95% on-time deliveries												X															**1**
82% to 98% customer delivery performance												X															**1**
Simulating																											
Supporting engineers in diagnosing and troubleshooting											X																**1**
Visual help and training for operators																			X								**1**
Easier identification of vulnerabilities																			X					X			**2**
Reduction of inconsistencies for more efficient processes																								X			**1**
Increased optimization possibilities													X														**1**
Minimizing manual work/ reduced manpower											X																**1**
Increased product quality																								X			**1**
Eliminated production loss											X													X			**2**
Automation																											
Warnings solved that are overlooked by operators									X																		**1**
Reduced manpower		X												X	X												**3**
Quick adaptation		X															X										**2**
Reduced risk				X				X																			**2**
Reduction of deployment costs with customized offerings																						X					**1**
Continuously improving										X																	**1**
Value adding for the whole ecosystem																						X					**1**
Lower costs and ecological footprint									X																		**1**

6.5. Present (Initial framework)

Synthesization of the MM from SLR 1, the VCR concepts from SLR 1 and SLR 2, and the VCA concepts from SLR 2, resulted in the initial framework. This framework can be seen in Figure 12 below. It represents an overarching framework that describes how OEMs can transform technologies into business opportunities for every phase toward Industry 4.0 maturity. It provides a handhold for OEMs on creating and capturing value for each phase of the Industry 4.0 MM, found in SLR 2 and SLR 1, respectively. These VCA concepts were supported by how the OEMs create value for the end-user and themselves.
Kapur et al. (2018) elaborate that implementing Industry 4.0 impacts maintenance and operations predominantly. Therefore, this research distinguishes between two disciplines: Maintenance and operations. For each phase in the model is described how value can be created and captured in these two disciplines.

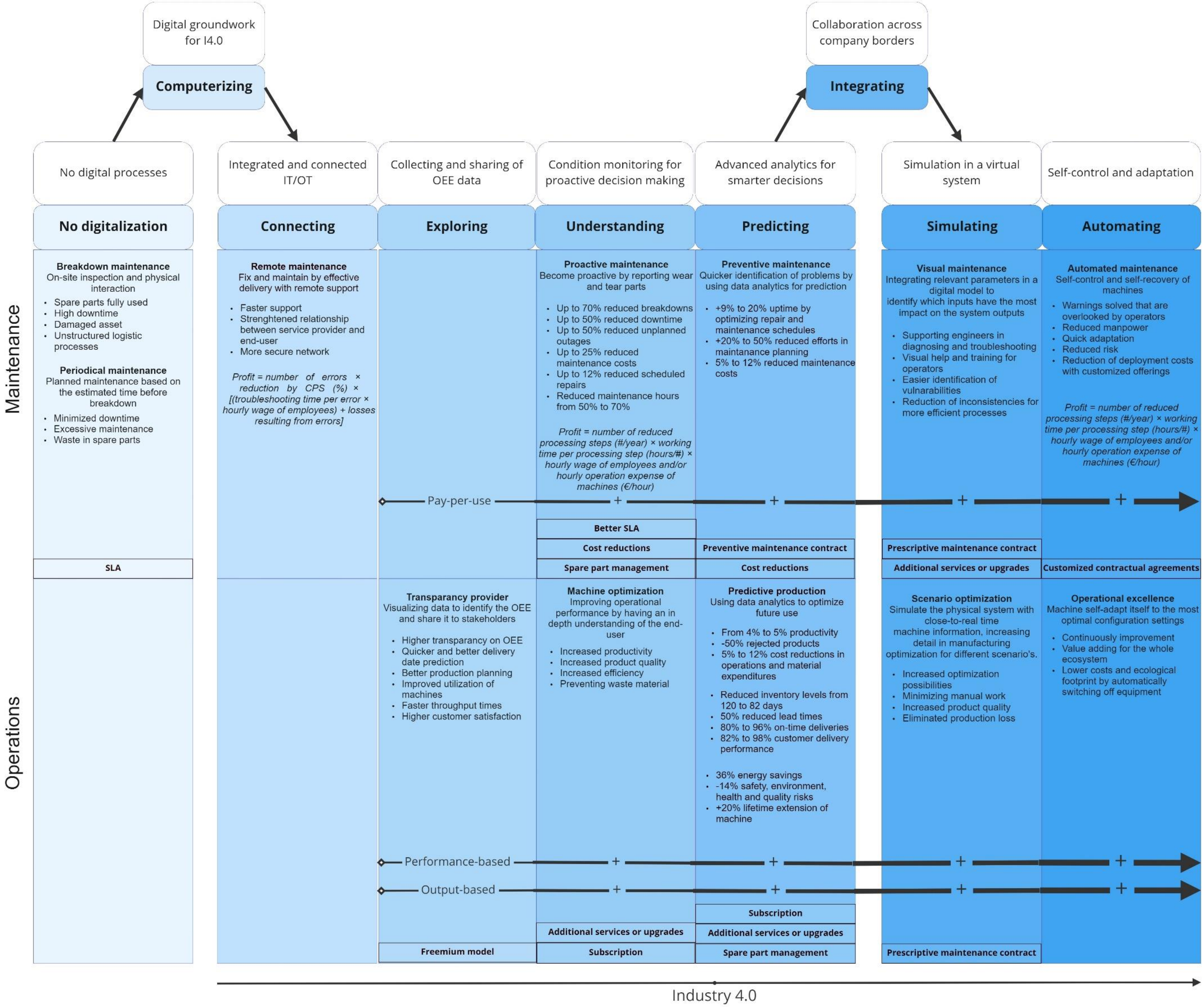

Digital groundwork for I4.0
Computerizing
Collaboration across company borders
Integrating
No digital processes
Integrated and connected IT/OT
Collecting and sharing of OEE data
Condition monitoring for proactive decision making
Advanced analytics for smarter decisions
Simulation in a virtual system
Self-control and adaptation
No digitalization
Connecting
Exploring
Understanding
Predicting
Simulating
Automating
Maintenance
Breakdown maintenance
On-site inspection and physical interaction
Spare parts fully used
High downtime
Damaged asset
Unstructured logistic processes
Periodical maintenance
Planned maintenance based on the estimated time before breakdown
Minimized downtime
Excessive maintenance
Waste in spare parts
SLA
Remote maintenance
Fix and maintain by effective delivery with remote support
Faster support
Strenghtened relationship between service provider and end-user
More secure network
Profit = number of errors × reduction by CPS (%) × [(troubleshooting time per error × hourly wage of employees) + losses resulting from errors]
Proactive maintenance
Become proactive by reporting wear and tear parts
Up to 70% reduced breakdowns
Up to 50% reduced downtime
Up to 50% reduced unplanned outages
Up to 25% reduced maintenance costs
Up to 12% reduced scheduled repairs
Reduced maintenance hours from 50% to 70%
Profit = number of reduced processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)
Preventive maintenance
Quicker identification of problems by using data analytics for prediction
+9% to 20% uptime by optimizing repair and maintenance schedules
+20% to 50% reduced efforts in maintanance planning
5% to 12% reduced maintenance costs
Visual maintenance
Integrating relevant parameters in a digital model to identify which inputs have the most impact on the system outputs
Supporting engineers in diagnosing and troubleshooting
Visual help and training for operators
Easier identification of vulnarabilities
Reduction of inconsistencies for more efficient processes
Automated maintenance
Self-control and self-recovery of machines
Warnings solved that are overlooked by operators
Reduced manpower
Quick adaptation
Reduced risk
Reduction of deployment costs with customized offerings
Profit = number of reduced processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)
Pay-per-use
+
+
+
+
Better SLA
Cost reductions
Spare part management
Preventive maintenance contract
Cost reductions
Prescriptive maintenance contract
Additional services or upgrades
Customized contractual agreements
Operations
Transparency provider
Visualizing data to identify the OEE and share it to stakeholders
Higher transparancy on OEE
Quicker and better delivery date prediction
Better production planning
Improved utilization of machines
Faster throughput times
Higher customer satisfaction
Machine optimization
Improving operational performance by having an in depth understanding of the end-user
Increased productivity
Increased product quality
Increased efficiency
Preventing waste material
Predictive production
Using data analytics to optimize future use
From 4% to 5% productivity
-50% rejected products
5% to 12% cost reductions in operations and material expenditures
Reduced inventory levels from 120 to 82 days
50% reduced lead times
80% to 96% on-time deliveries
82% to 98% customer delivery performance
36% energy savings
-14% safety, environment, health and quality risks
+20% lifetime extension of machine
Scenario optimization
Simulate the physical system with close-to-real time machine information, increasing detail in manufacturing optimization for different scenario's.
Increased optimization possibilities
Minimizing manual work
Increased product quality
Eliminated production loss
Operational excellence
Machine self-adapt itself to the most optimal configuration settings
Continuously improvement
Value adding for the whole ecosystem
Lower costs and ecological footprint by automatically switching off equipment
Performance-based
Output-based
+
+
+
+
+
+
+
+
Subscription
Additional services or upgrades
Additional services or upgrades
Freemium model
Subscription
Spare part management
Prescriptive maintenance contract
Industry 4.0

Figure 8: Initial framework

Though, the literature did not describe how value can be captured in two phases in the model, Computerizing and Integrating. Computerizing counts for the preparation required to implement the first Industry 4.0 technology in the Connecting phase. The same applies to the Integrating phase, in which integrating external concepts serves as a stepping stone toward automation in the subsequent phases. Hence, no value is created directly for the end-user, implying that no value can be captured in each phase.

The VCR and VCA blocks will be described for each MM phase, starting with No digitalization.

6.5.1. Maintenance

6.5.1.1. Breakdown -and periodical maintenance

Maintenance is carried out in the traditional way when there is no digitalization. One possible way to do this is to have the end user call the service engineer of the OEM when the machine breaks down. This is called breakdown or corrective maintenance (Caiado et al., 2021; Xia et al., 2019). In this case, the service engineer has to come on-site to detect and repair the error (Caiado et al., 2021; Deloitte, 2017). This is a highly unstructured logistic process (Caiado et al., 2021). The traveling and repair time causes high downtime, which harms production and, therefore, causes losses in profit (Deloitte, 2017). An additional drawback is that the failure can cause damage to the machine. The advantage here is that the parts in the machine are used optimally (Deloitte, 2017).

The second option is periodical maintenance (Caiado et al., 2021; Xia et al., 2019). In this case, OEMs replace components before the breakdown, based on the estimated lifetime of the component. This minimizes production losses compared to breakdown maintenance since it can be performed on pre-scheduled intervals outside production hours. The downside of this is that maintenance has to be done frequently. Also, spare parts are wasted since the estimated lifetime is imprecise and differ for every other purpose (Deloitte, 2017).

These maintenance services are often included in a service level agreement (SLA). This is the way in which OEMs derive revenue from services. SLAs are measurement instruments for specific agreements about the functionality of a machine. These contracts promise the end-user that maintenance is executed on the machine during its lifetime. These agreements can be aimed at the availability or performance of the machine, for example (Häckel et al., 2022).

6.5.1.2. Remote maintenance

Just as in the "No digitalization" phase, is the maintenance plan still reactive (Rockwell, 2014). The exact maintenance procedure applies, where the end-user calls the OEM whenever a problem with the machine occurs. Although, the VPN connection implemented in this phase makes remote maintenance possible (Rockwell, 2021; Schuh et al., 2020). Hence, the service engineer can remotely access, program, and manage the broken asset from a PC or another internet-enabled device (Jæger & Halse, 2017). Therefore, the focus is still on fixing and maintaining the asset but can be mainly done remotely at the OEMs' location (Jæger & Halse, 2017; Schuh et al., 2020).

This solution reduces the traveling time for the service engineer. This traveling time has a direct negative influence on the salary of the service engineer and the rising losses by stand-still of the machine. All these costs mentioned are, in most cases the responsibility of the OEM if the machine breaks down. The following formula by Burggraf et al. (2018) calculates the profit that can be obtained by completing the Connecting phase:

Profit = number of errors × reduction by CPS (%) × [(troubleshooting time per error × hourly wage of employees) + losses resulting from errors]

It accounts for the number of errors at a machine, the difference in both situations regarding salary, and resulting losses for the end-user.

6.5.1.3. Preventive maintenance

How maintenance is conducted in this phase shifts from a reactive to a proactive manner (Rockwell, 2021). With breakdown maintenance and remote maintenance described in previous stages, the machine must first break down before action is required. When OEMs know the critical components of a machine and how they can extract the right information to monitor these, they can take action before the machine breaks down (Schuh et al., 2020). If the data is continuously monitored, the OEM can keep an eye on so-called wear and tear parts in real time (Fraunhofer & VDMA, 2021). It allows for identifying problems before they even occur with a high degree of precision, enhancing the machine's process reliability (Fraunhofer & VDMA, 2021; Schuh et al., 2020). Hence, there is less likelihood that a breakdown will happen, and when it happens, downtime remains minimal (Deloitte, 2017; Passlick et al., 2020). IBM (2017) has measured that condition-based monitoring can even decrease breakdowns by up to 70% and unplanned outages by up to 50%. In addition, downtime will be reduced by up to 50%. The result is that service engineers have to spend less time on maintenance, decreasing from 70% to 50% (IBM, 2016). The end-user machines' availability and productivity increase significantly, which value can be captured in several ways.

The first option is to upgrade their SLA (Li & Tomlin, 2022; Schuh et al., 2020). SLAs are traditionally used to agree on how the OEM grants service to the end user. Agreements on the machine's performance, uptime, and responsiveness are Captured in a contract, where a penalty is given when the requirements are not met, or an incentive is given when it is met (Schuh et al., 2020). An SLA can also be established with a long-term service contract that can be paid in two ways. One is that the end-user pays per unit uptime (or penalty per downtime). The other one is a fixed payment, such as a quarterly fee. In the last case, the contract does not depend on uptime (Li & Tomlin, 2022).
In both cases, condition-based maintenance is required to set up a better SLA than before. A requirement here is that the OEM has to guarantee a higher machine availability with minimum risk (Schuh et al., 2020). This can either enhance competitiveness or a better price for the actual contract. For example, Trane is an HVAC manufacturer that can offer better SLAs by monitoring its equipment. They use data to determine whether a motor is at risk and calculate how long it takes to break, so that the service engineer can work on the correct component at the right time. As a result, they can offer better SLAs to their customer. Trane says: "For every dollar we make from product sales, we have the potential to make twelve dollars in aftersales. At present, our product and service turnovers are virtually identical. But services are much more profitable" (Schuh et al., 2020).

Besides capturing value, OEMs can also create value for themselves by reducing their own maintenance costs (Rockwell, 2021). IBM (2017) states that the maintenance costs for the OEM decrease by up to 25%. The number of scheduled repairs can also decrease by up to 12% (IBM, 2016). OEMs can easily calculate the cost reduction through real-time monitoring of the equipment (Burggraf et al., 2018). The following formula counts for the profit retrieved by decreasing failures, reduced troubleshooting, and losses from these failures:

Profit = number of additional processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)

In this phase, the OEM is able to know on forehand which components are about to break down. It makes it possible to know which spare parts have to be sold and OEMs can react to this. This procedure prevents the end-user from skipping the OEMs service and choosing another supplier, which causes losses in sales (Deloitte, 2020)

6.5.1.4. Predictive maintenance

Compared to the previous phase, a more proactive maintenance effort is emphasized in the Prediction phase. An improved monitoring and control procedure is established in this phase (Burström et al., 2021). Where the understanding phase prevents failures based on observations, the Prediction phase predicts system failures and discrepancies on the forehand (Benešová et al., 2021). This makes the maintenance efforts more reliable because OEMs can anticipate faster and easier when a failure can be more accurately predicted long before it breaks (Caiado et al., 2021; D. R. Sjödin et al., 2018). Smarter decisions can be made, which could increase usage and minimize downtime (Caiado et al., 2021; Deloitte, 2017). It makes it possible to know in advance what could happen, leading to better production reliability and profits (Lee et al., 2017).
Costs again decreased from 5% to 12%, with respect to the reductions in the Understanding phase (Passlick et al., 2020a; PwC, 2018). One of the reasons for this decrease is that repair and maintenance schedules were improved (PwC, 2018). Hence, efforts in maintenance planning have decreased from 20% to 50% (Deloitte, 2017).
Asset uptime can also be improved by using predictive algorithms on critical assets (PwC, 2018). Deloitte (2017) notes that optimizing maintenance schedules can yield another 9% to 20% uptime improvement.

An advanced manner of monitoring and controlling the process results in a more detailed and predictive overview of the machine's health. The uptime improvements again ensure that better service contracts can be set up. Burström et al. (2021) state that this feature enables OEMs to set up preventive maintenance contracts and offers these to the end user. These include early warnings and a reduction in the number of breakdowns. These contracts are managed by teams of the OEM that give back-end support by informing the end-users of potential problems and irregularities. An IT manager describes: "Our customers were not very receptive to our AI-enabled optimization-based services as they thought it was costly. But with many successful customer cases, we can show the numbers of how our other leading customers managed to gain from such an offering" (Burström et al., 2021).
Additionally, the operational costs were reduced because many interactions were eliminated by automation. That also led to better response time and improved monitoring (Burström et al., 2021).

For this reason, customer value and satisfaction enhances at first (Häckel et al., 2022). Nevertheless, it also enhances profit in services. That is because a better risk analysis can be made based on the end-user's previous record. Sales personnel had a portfolio of bad and good service contracts. By using AI, the personnel can do better analysis of the pricing level to take out contracts that were potentially risky or costly (Häckel et al., 2022).

6.5.1.5. Visual maintenance

In the simulation phase, the OEM has built a virtual and dynamic representation of the machine in the real world that makes use of analytical streaming techniques (Mostafa et al., 2021). OEMs can integrate relevant parameters into the virtual model to observe a change a difference in output. OEMs can identify which parameters have the highest impact on the system that could cause downtime (Damant et al., 2021). If all states of the system are known, more intelligent decisions can be made (Weber et al., 2017).
This has various benefits for maintenance. First, it helps service engineers to recognize the cause of the failure. Service engineers do not have to be on-site to identify the failure but can already observe this in the virtual model. Additionally, the visual model also can help operators to run the machine and can be used as a training system (Deloitte, 2020). Most of the issues that cause downtime can be eliminated before it starts to harm production (Mostafa et al., 2021). Thirdly, efficiency increases by reducing inconsistencies in the process (Damant et al., 2021; Deloitte, 2017). This saves considerable costs and time (Mostafa et al., 2021). Fourthly, the machine already shows some adaptivity by reducing breakdowns itself (Mostafa et al., 2021). For example, when a machine learning model raises an alarm, the digital twin seeks for causes in the model. It changes the concerned input parameters to control physical entities such as a valve or cooling system (Mostafa et al., 2021).

The OEM can VCA these benefits in two ways. First, easy identification of vulnerabilities enables the OEM to offer additional services when a machine is not operated the way it should be (Deloitte, 2020; Kampker et al., 2022). Deloitte (2020) explains that customers can be targeted more easily with services, training or upgrades when downtime is recognised. For example, an OEM that produces harvesting machines can simulate a digital potato and identify if it experiences too many shocks. Here, a recommendation can be made for correction of machine parameters. This enhances the availability of the machine in the future (Deloitte, 2020).

On the other hand, OEMs can set up prescriptive service contracts (Burström et al., 2021). With these contracts, the sales and service organization can suggest proactive actions for extension of the lifetime of the machine (Burström et al., 2021; Deloitte, 2020). These contracts shows which parameters can be changed to optimize uptime. These recommendations are based on AI or machine learning models that search for existing patterns in historical data (Burström et al., 2021).

6.5.1.6. Automated maintenance

The machines in the previous phase show adaptation to some extent, whereas the machines in this phase can adapt to the environment as quickly as possible (Schuh et al., 2020). AI or machine learning models can diagnose abnormalities in production, and machines can recover from them without human assistance (Lee et al., 2017; Schuh et al., 2020). IT systems take over most of the maintenance (Schuh et al., 2020). This results in a reduction in the workforce, which can save costs and time for the OEM. The profit that can be made with this cost reduction can be described with the following formula (Burggraf et al., 2018):

Profit = number of reduced processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)

Also, causes of potential failures that operators usually overlook can now be eliminated (Fraunhofer & VDMA, 2021). This reduces the number of risks significantly, even as security risks (Leyh et al., 2016; Rockwell, 2021).

Integrating external concepts in the Integration phase can transform how business is done (Rockwell, 2021). Networked collaborations with suppliers, customers, and business partners make it possible to exchange information and regulate the machine automatically based on this information. This enables OEMs to develop new end-to-end solutions and BMs (Leyh et al., 2016; Xia et al., 2019). Burggraf et al. (2018) mention customized contractual agreements that are enabled here. As a result, deployment costs for these customized offerings reduces (Burggraf et al., 2018).
The OEM still needs to analyze the data via the digital twin. Instead of recommending a solution for changing parameters, the machine adjusts the parameters itself. Therefore, the OEM does not have to become active itself. The core of this BM is that the solution provider does not offer the machine itself, but the intended outcome the machine delivers (Kampker et al., 2022). Here, the focus shifts completely from product-oriented to service-oriented, where business models evolve into an innovative structure (Gökalp et al., 2017; Xia et al., 2019).

6.5.2. Operations

6.5.2.1. Transparency provider

Many end-users have no systems to monitor their KPIs or OEE and have no feedback on how strategic decisions influence the system (Fraunhofer & VDMA, 2021). In this phase, OEM has collected the most important production data of the machine (Weber et al., 2017; Xia et al., 2019). This data visualized on a dashboard can provide transparency into the machine's OEE, such as efficiency and productivity (Fraunhofer & VDMA, 2021; Schuh et al., 2020; Weber et al., 2017). With this information, the end-user is able to enhance production planning since it becomes more transparent. Better production planning leads to better machine utilization and better throughput times. Also, inventory requirements become more predictive (PWC, 2016; Schuh et al., 2020; D. R. Sjödin et al., 2018). Knowing output of the machine enables it to determine the delivery date more quickly and precisely (Schuh et al., 2020).

Foreseeable sales, capacity utilization and customer histories are known to the OEM, so that pricing models can be used to offer new contract models. For example, OEMs can improve their after-sales service thanks to product feedback during use (Schuh et al., 2020)

Gebauer et al. (2020) mention another type of VCA method that is used in the Exploring phase; Freemium models. Here, the OEM can offer the end-user a free trial to let them experience the benefits over some time. After that, it may feel like a loss of benefits, which makes the end-user buy a subscription (Gebauer et al., 2020). For example, a food processing OEM has offered a freemium model to their customers to monitor thermal KPIs, directly increasing the OEMs revenues from 75.000 to 100.00 euros.

6.5.2.2. Machine optimization

Whenever the OEM understands the data and can contextualize it, information can be transformed into insights. Organizations have built competencies by learning from their machine and optimizing these in the future. Here, the focus shifts toward benefitting from the data (Sjödin et al., 2018). The organization is now able to improve the operational performance of the machine (Passlick et al., 2020a; PWC, 2016; Rockwell, 2014). Smart tools may help improve the process's efficiency (Rockwell, 2014; Xia et al., 2019). Also, productivity increases and quality improves by optimization of relevant parameters (Rockwell, 2014). Besides, costs decrease when waste material is prevented (Passlick et al., 2020a; D. R. Sjödin et al., 2018). These improvements are prioritized because of the continuous optimization of condition monitoring (Rockwell, 2014; Sjödin et al., 2022). Consequently, customer experience and customer loyalty enhance throughout the process.

However, it is hard to VCA these benefits. One way to generate revenue from this created value is to provide additional services. Schuh et al. (2020) explain that the OEM can provide additional optimization services to make the machine run more efficiently. For example, by monitoring with a cloud solution, OEMs can identify what changes in parameters make the machine run smoothly and generate one-time profits from this. Thus, end users pay a fixed amount for an increase in operation optimization described above, such as productivity, quality, efficiency, or cost reduction.

6.5.2.3. Predictive production

The vast majority of operational improvements can be identified in the Understanding phase where insights are extracted by visualities in the data. For the more complex causalities, data analytic tools are required, such as AI or machine learning (Fraunhofer & VDMA, 2021; Gökalp et al., 2017). The proceedings are still carried out manually by humans, but supported with tools to find optimization possibilities that could not be recognized by observation (Schuh et al., 2020). Historical data of unforeseen events are analyzed and interpreted, which serves as a new pattern for future use (Burström et al., 2021; Gökalp et al., 2017; Schuh et al., 2020). That makes it possible to evaluate the throughput of the machine, so that machine parameters can be reconsidered and changed (D. R. Sjödin et al., 2018).
Hence, former companies have shown that productivity can be improved from 4% to 5% (Burström et al., 2021; Rockwell, 2021). Also, the quality of the products enhances when the number of rejected products decreases by 50% (Rockwell, 2014). A digitalization lead of an OEM describes: "At the end, with AI power, we can truly utilize the extensive data that we have been generating for higher customer value. When we moved into optimization services, we became fully engrained into customer operations, and their operational performance became our priority" (Burström et al., 2021).

Data analytics are also used to employ proactive processes regarding forecasting and planning of future production (Caiado et al., 2021; Sjödin et al., 2018). As a result, the end-user knows in advance what to expect to make the right decisions in good time (Schuh et al., 2020; Sjödin et al., 2018). So has Rockwell (2021) investigated case companies where inventory levels are reduced from 120 to 80 days. In addition, it has been proved that forecasting positively affects delivery date prediction. So have the on-time supplier deliveries risen from 80% to 96%. Also, customer delivery performance has risen from 82% to 98%. Lastly, the lead times have been reduced by 50% (Rockwell, 2021).

The created value in can be captured by more accurately selling spare parts (Deloitte, 2017, 2020; D. R. Sjödin et al., 2018). By detecting earlier failures in the maintenance procedure, the OEM can inform the customer more precisely when the part breaks and make an offer on the right spare parts. A production planning tool is triggered to pop-up a warning on the day it breaks down (Deloitte, 2020).

Another concept where technologies in this phase can be Captured are subscription models (Häckel et al., 2022; Passlick et al., 2020a). The functionalities that come with AI and forecasting services are Captured in a subscription model that is paid on a fixed-time basis, such as monthly or yearly. The fee is independent of the times that the service is accessed (Häckel et al., 2022; Passlick et al., 2020). Here, the end-user can use the analytic data models that come with forecasting any moment of the day according to the contract specification (Passlick et al., 2020).

Prediction do also have a positive effect on sustainability concepts. The downtime and failure rates identified in the maintenance procedures can be analyzed and predicted to transform into a sustainable factory economically and ecologically (Sjödin et al., 2018). An energy reduction of 36% can be reached, as known from best-practices (PwC, 2018) Analyzing unforeseen events can increase the lifetime of an aging asset by 20%, which increases durability (PWC, 2016; Sjödin et al., 2018). AI can optimize specific outcomes by changing demands and seeking the most optimal usage rate (Burström et al., 2021; Deloitte, 2017). For example, the time between maintenance can be adjusted to predefined objectives. An optimal usage rate can even reduce emissions to 10%. Overall, using predictive analytics can reduce environmental, quality, safety, and health risks by up to 14% (PwC, 2018). Or as explained in the Understanding phase, the OEM can provide additional services to increase the machine efficiency (Schuh et al., 2020). This option consists of a is a one-time upgrade and less binding as contracting.

By identifying the usage of machines, underutilized equipment can be remarked. Wang et al. (2020) state that OEMs can lease underutilized equipment to others that need it urgently. Here, the value can be captured in dynamic leasing contracts. From a sustainable aspect, it improves the usage rate and reduces waste (Wang et al., 2020).

6.5.2.4. Simulation optimization

A digital twin makes it possible to take data analytics to the next level by simulating the physical system through the entire lifetime with real-time streaming techniques (Deloitte, 2020; Mostafa et al., 2021). The virtual system can simulate several scenarios to enhance real-time optimization (Xia et al., 2019). All the input parameters are integrated to experience the most optimal outcome (Damant et al., 2021). As a result, the virtual system can be simulated before the physical system is up and running. Therefore, most of the issues in the physical system can be eliminated before production has started (Mostafa et al., 2021). As a result, product failure decreases and the quality of the machine increases (Damant et al., 2021). This saves both costs and time because ETL and machine learning procedures are mostly automated.
Going one step further is developing a super digital twin, where individual systems are integrated and the whole manufacturing plant can be modelled to optimize the operations of the entire factory (Mostafa et al., 2021). With these new streaming techniques, the OEM is able to establish better prescriptive maintenance contracts concerning the previous phase. According to Burström et al. (2021), prescriptive service contracts based on simulation models can provide end-users with optimizations initially missed by service engineers or sales personnel. It enables end-users to make the most out of their machine. This can be suggestions on operational improvement of scheduling maintenance, for example.

6.5.2.5. Operational excellence

The final phase of operational excellence accounts for continuous adaptation and process improvement (a developed). Advanced analytics are employed in a feedback loop which results in automated optimization and decision support based on Big data (Benešová et al., 2021; PWC, 2016; Weber et al., 2017). All these concepts enable self-learning continuously (Weber et al., 2017). Whereas the analysis of information already offered

value to the optimization and planning of the production, will the automation of these processes even add more value (Burström et al., 2021; Fraunhofer & VDMA, 2021).
The integration and collaboration of the whole value chain enable the optimization of value networks and information flows (Leyh et al., 2016; Lin et al., 2020). Hence, the value created and captured reaches beyond the OEM boundaries (Burström et al., 2021). This introduces new innovative business models and end-to-end solutions in a business ecosystem (Burström et al., 2021; Leyh et al., 2016). The added value created here is the complementary roles and rules with value chain stakeholders that can be Captured by offering customized contractual agreements (Burström et al., 2021). As a result, deployment costs that are associated with these offerings reduce (Burström et al., 2021). However, Burström et al. (2018) indicate that current research still aims for optimization but can not translate these benefits into revenues.

6.5.3. General VCR and VCA concepts

In the entire maintenance discipline is optimal performance of the machine central to each phase. As such, decreasing the amount of breakdowns, minimize the breakdowns and reducing risks are main objectives these phases. Thus, completing a phase in the MM enhances the availability and uptime of the machine as such that the uptime of the machine increases significantly. Consequently, OEMs can drastically transform their product-oriented BMs into service-oriented BMs.

One way to benefit from the increase in uptime of machines are performance-based BMs (Burström et al., 2021; Gebauer et al., 2020; Häckel et al., 2022; Sjödin et al., 2022). Performance-based BMs can be applied for each phase in the Industry 4.0 MM (Agarwal et al., 2022; Burström et al., 2021; Deloitte, 2020; Gebauer et al., 2020; Kampker et al., 2022; Kohtamäki et al., 2019; Linde et al., 2021; Schaefer et al., 2017; Sjödin et al., 2022). This is only the case if machine uptime is known by the OEM, which is here starting in the Exploring phase. The reason for this is that no data is monitored yet in the Connecting phase.
With performance-based BMs, the machine stays in ownership of the OEM and the end-user only pays for the time that the machine is up and running. The increased uptime in each of the phases makes it interesting for OEMs to sell their machine based on the performance of the machine to maximize revenues from the value that is created (Gebauer et al., 2020; Li & Tomlin, 2022). Here the goal of the OEM shifts from selling equipment towards providing excellent service. The main focus of the OEM is ensuring that the availability of the equipment, valuable production time and lifetime is maximized. In this case, the recurring profits derived depends on the quality of service that is provided (Sjödin et al., 2022).
Another BM that is are also profitable with an increase in availability, are pay-per-use BMs (Gebauer et al., 2020). Again, pay-per-use models are also applicable for all Industry 4.0 phases, starting from Exploring (Arnold, 2017; Chen et al., 2021; Deloitte, 2020; Gebauer et al., 2020; Häckel et al., 2022; Linde et al., 2021; Müller, 2019; Passlick et al., 2020a; Schaefer et al., 2017). In this case, the machine stays also in ownership of the OEM, but the end user pays here for the time the machine is in use (Deloitte, 2020; Gebauer et al., 2020).
In conclusion, both performance-based and pay-per-use BMs are ways to VCA the value that is created throughout the entire maintenance phase. It enables to translate the availability of the machine into revenues.

In the operation discipline is the optimalization of the machine central to each phase. As such, productivity and less rejected products are aspects that account for an increased performance of the machine per phase completed.
One way to benefit from the increase in productivity and quality is to apply output-based BMs (Li & Tomlin, 2022). Again, this model is applicable for the entire Industry 4.0 MM, starting from Exploring with the same reason as described before (Agarwal et al., 2022; Deloitte, 2020; G. Schuh et al., 2018; Kohtamäki et al., 2022; Li & Tomlin, 2022; Sjödin et al., 2022). The ownership of the machine is still with the OEM, whereas the end user pays for the output of the machine. In this case, the OEM is able to capture the value that is created by optimizing the machine. Together with the maintenance activities is the operation discipline responsible for the performance of the machine. Increasing the output with maintenance and operations in each phase can ensure that profits are maximized. For example, Deloitte (2017) explains that an OEM that produces printing presses uses an output-based BM to earn for every page that is printed, which ensures a better cash flow and flexibility.

They are also able to thrive revenue with consumables and spare-parts, as they know what the output of the machine is. End users experience the benefits with budgeting and forecasting. In conclusion, the activities in each phase of the maintenance and operation discipline ensures a higher performance of the machine. This value can be captured by earning money per output of the machine.

In all three BM structures changes the financial status of the OEM drastically. Hence, the one-time sales of machines are replaced with recurring revenues from performance-based of pay-per-use BMs. The financial status of the OEM changes, as they lose large profits by skipping the one-time sales of machines. These can be tackled in three off-balance ways: Financing via strategic partners or financing institutions that account for the financing of the machine or the machine is bought regularly by the end user. With the last option, the traditional process comes into place, where the pay-per-use BM of performance-bases BM only refer to the service and the optimization. These measures ensure that the fixed assets on the balance sheet increasing while cash decreases. Here, the end-user is not stuck to long-term investments.

7. Empirical research with TCP

This section accounts for the remaining research question that help to answer the main research question. The fourth research question (RQ4) state: "*How can the initial framework be adjusted to enable a good fit for the TCP market?*". An empirical study can answer the abovementioned question. It will be used to extend knowledge by filling the gaps in the literature and validating the retrieved results from the literature.
The MM, even as the VCR and VCA concepts, are evaluated within the same empirical study. That means that the initial framework derived from the literature will be aligned to TCP. In order to achieve this, an empirical study is performed together with IXON Cloud, whose customers are known as TCP. IXON Cloud offers various end-to-end IoT solutions to the TCP, ensuring that the TCP can improve services and operations. However, IXON Cloud experience that the TCP is hesitant to adopt because they can not transform these end-to-end solutions into business opportunities yet. The established initial framework can help OEM to identify business opportunities, but it is not limited to the TCP yet. As explained, the current framework from literature does not account for a realistic view of the current status of SMEs regarding Industry 4.0 maturity, VCR, and VCA. Hence, this empirical study is conducted to extend and validate the information resulting from SLR 1 and SLR 2, making the final framework fit the road to maturity and business opportunities that the TCP experience in practice.

Qualitative research was found to be the most suitable method to answer the last research question. Qualitative research makes it possible to retrieve novel answers, as well as validation of findings from theory. It allows for a more explorative way of extracting information. This method is chosen over quantitative research, because the reasoning behind a statement is evenly important as the statement itself (Maanen, 1979). Also, suggestions and corrections are vital to strengthening the framework. More specifically, interviews are used as a qualitative data collection method. Two types of interviews were executed to retrieve information from two different kinds of actors. The first type of interview is with the TCP itself, and the second is with Industry 4.0 experts that are involved in TCP's Industry 4.0 transformations.

7.1. Designing the interviews

This research followed an interview guideline proposed by Rowley (2012) throughout this empirical study section. It explains why interviews were conducted and how they were designed, carried out, analyzed, and demonstrated for research purposes.
In the first step, it is vital to understand why qualitative research can contribute to this research. Interviews make it possible to validate insights that are found in SLR 1 and SLR 2, but also allow for novel insights that were initially not known by the researcher (Creswell, 2014). Therefore, the interviews seek to elicit information from TCPs about their journey to the current Industry 4.0 state, as well as their best practices for leveraging Industry 4.0 technologies to create business opportunities for VCR and VCA.
In the second and third step, it is vital to determine the type of interview most suitable for this research(Rowley, 2012). The type of interviews is chosen to be semi-structured. This is the most common way of interviewing and most suitable for this research (Rowley, 2012). Semi-structured interviews made it possible to validate, but also extend the initial framework with insights the researcher did not found in the SLRs on forehand (Kvale, 2012). These kind of interviews ensured that all mandatory questions were addressed, while also allowing for in-depth questioning when something was unclear or additional information was required (Galetta, 2012). Despite the standardized protocol, the researcher left room for additional inquiries if needed (Kvale, 2012) This is especially important when the researcher requires additional information about a MM phase or VCA concept that is unclear. For example, an interviewee stated that value is captured with Industry 4.0 by a certain contract. The interviewer could now ask a follow-up question to elaborate on the details of that contract, which was initially not embedded in the interview. In this case, the researcher had the ability to ask the required amount of questions to fill the information gap.

The fourth step in the guideline of Rowley (2012) accounted for the participant selection and length of the interview. As a rule of thumb, an interview with a duration of 30 minutes is considered good, holding into account several concepts such as willingness to participate and the effectiveness of the interviewee (Rowley, 2012). Also, many researchers have debated how many interviews are required for a reliable source of information. According to Patton (1990), there is no minimum or maximum limit of respondents, elaborating on the fact that there are no rules regarding sampling. Some researchers state the minimum of participants is reached whenever new participants do not provide additional information; thus, saturation is reached (Glaser, 1992; Morse, 1995). Saturation is reached whenever little or nothing new is added to the coding scheme (Guest et al., 2006). Lincoln and Guba (1985) add that redundancy of information at one point could also be a reason for saturation. Research that actually quantifies the minimal amount of interviews is Creswell & Poth, 2007, mentioning that five interviews are at least a minimally acceptable amount of participants. Guest et al. (2006) discovered that 94% of the information was extracted after six interviews, while 97% was covered after twelve interviews. This finding shows that new insights drastically declined after six interviews were taken.

Summarizing, research does not agree about the ideal number of participants in qualitative research. Following these findings, this research used at least six participants while stopping by adding more participants to the dataset whenever saturation or redundancy was reached.

7.2. Selection of participants

The fifth step in the guideline of Rowley (2012) was to select and enlist the potential interviewees. It was critical to select the right interviewees and companies when conducting interviews in order to extract the necessary information. In this case, information from best practices of the TCP themselves would have provided the most realistic information in practice. For this reason, the interviews have been conducted with the TCP that were yet capable of creating and capturing value within one or more phases of maturity. Nevertheless, a realistic viewpoint of the TCP itself was not be sufficient for assessing the framework on all maturity phases, VCR, and VCA. In addition, most of the TCP are still unsure how to VCA value with Industry 4.0 technologies and transform business, as described in the Theoretical background. Hence, Industry 4.0 experts have been added to the sample in addition to the TCP itself. It empowered the assessment of the framework outside TCP's application area and provides a more comprehensive view of the possibilities, providing a future-proof vision of the MM, VCR, and VCA that experts experience with the TCP. These insights gave a more comprehensive view of the market, next to the current state of TCP. These experts contributed to this research by adding valuable insights into maturity phases that OEMs in the sample are not able to assess, and validate ways of VCR and capturing that the current TCP is not aware of. Therefore, the sample of participants is a mix of TCP, either customers or non-customers of IXON Cloud, and independent experts of Industry 4.0.

Three criteria are predefined to ensure that the participants meet the conditions to ensure a good fit to the interview.

1. The interviewee should work at a company within TCP boundaries that has Industry 4.0 applied to their business, or either:
   1.1. Is an expert in Industry 4.0 and is involved in cooperating with TCP in applying Industry 4.0*.
2. The interviewee holds a function within the company where Industry 4.0 plays a major role, such as a service engineer or sales manager.
3. The OEM has completed at least one phase in Industry 4.0 of the MM, as assessed by the researcher on the forehand.

Internet searches and expert opinions within IXON Cloud formed the basis for constructing a list of potential companies to interview. A second selection was derived carefully to ensure that the final sample was aligned with the research goal. Here it is critical to enable a high diversity of maturity phases completed by the sample. A sample with an equal distribution of maturity phases allowing for the majority of the initial framework to be tested. It is not making sense to establish a sample with TCP that only execute remote access while not assessing companies that use AI. Also, bias has been avoided by ensuring an equitable distribution of industries in which the TCP works.

The procedure for approaching the selected companies was to call the company by telephone when the company was unknown. The researcher had to verify who is responsible for Industry 4.0 in the company and has knowledge of both implementation and business side. Mostly, these are service managers or innovation managers. If the company or interviewee was known to the researcher, the company/interviewee was called directly. Calling the participants is considered to be a more effective way of approaching the target group. The potential group of interviewees with whom it was possible to make an appointment can be seen in table 10. All names are anonymized with respect to the interviewees.

Table 10: Sample of participants

Interviewee(s)	Job title	Company	Company Type	Company Size	Industry	Industry 4.0 application(s)
Interviewee 1*	Manager Innovation and Technology	A	Engineering agency (ambassador of Smart Industry)	100-150	High-tech	Remote access, data logging, AI
Interviewees 2 and 3	Service manager and Software manager	B	OEM	100-150	Food processing	Remote access, digital twin
Interviewee 4	System control engineer	C	OEM	100-150	Food processing	Remote access, data logging, digital twin
Interviewee 5	Service Coordinator	D	OEM	20-50	Robotics	Remote access, data logging, digital twin
Interviewee 6	Manager Logistics & Control	E	OEM	150-250	Food processing	Remote access, data logging
Interviewee 7	Customer support engineer	F	OEM	20-50	Robotics	Remote access, digital twin
Interviewees 8 and 9	Manager Service Strategy, Software engineer	G	OEM	150-250	Printing	Remote access, data logging
Interviewee 10*	Industry 4.0 consultant	H	Conglomerate (digital services)	>100.000	Industrial automation	Industry 4.0 (all)

*= Expert in Industry 4.0

This resulted in a participant sample of eight companies. The following participants were selected based on the predefined conditions and a diverse mix of application areas. Here, companies B to G provided a realistic view of the current status of the TCP, covering the application areas “remote access”, “data logging”, “AI”, and ”digital twin”. These aspects may cover the majority of the Maturity phases. On the other hand, two interviewees are added that are experts in Industry 4.0, working by companies that consult the TCP on their Industry 4.0 capabilities. So, companies A and H can complement the existing knowledge base and give insights into the phases not covered by the TCP. The latter two companies have a broader perspective on how the MM, VCR, and VCA could look like, since they serve a more extensive base of TCP and have higher expertise on the topic. More specifically, interviewee 10 of Company H has knowledge of all Industry 4.0 application areas.

In conclusion, ten representatives were interviewed, divided over eight companies. From this sample, six of them are TCP that have integrated one or more Industry 4.0 technologies into their company. Two of them are Industry 4.0 experts that guide TCP in its Industry 4.0 journey.

7.3. Conducting the interviews

The sixth, seventh, and eighth step in the guideline of Rowley (2012) are all related to conducting an understandable and fluent interview. Here, two types of interviews were developed, one for the Industry 4.0 participants and one for the Industry 4.0 experts mentioned in the previous section. This is the case because the outcome of both SLR required practical information of the current state of TCP, but also an overarching view of the market and future developments. Both interviews were divided into two parts, indicating the goal of this empirical study: extension and validation of the initial framework. In the extension phase, the interviewee have not seen the initial framework, which ensured that the interviewee will think deeply about the matter rather than verify the aspects seen in the framework. That is, the interviewee described their own road to Industry 4.0 maturity, rather than just verifying the initial framework. This enhances the creation of novel insights and reliability of this research (Kvale, 2012). Validation of the interview will cover the remaining aspects that the interviewee forget to mention or corrections to the findings in the initial framework. That is, reflecting on the MM and its VCA and VCR components.

Preliminary research is executed to reduce the number of unnecessary questions potentially to be asked. It ensured that personal and company-related information was known on the forehand. Simple information that could be found through online searches, such as firm size, job title, and industry, should not have been requested in the interview. This information was extracted via the website, LinkedIn, or cleared by the interviewee on the telephone or via e-mail. As a result, the interviewer can dive directly into valuable information.
A pilot interview was executed to check whether the interview questions fit the goal of this research question and could trigger additions and corrections to the findings from both SLRs. Moreover, it was checked if the interview questions made sense and were logically structured. Moreover, the interview questions should fit the goal of this research question and provide additions and corrections to the findings from both SLRs. Two ways of a pilot interview were to conduct internal testing and external assessment. The first accounted for testing the concept interview with critical information from the research team, and the latter by assessing the interview with an expert outside the research team (Kallio et al., 2016). For this research, both concepts are applied. These two pilot interviewees were one internal and external participant, both working at IXON Cloud.
These two pilot tests resulted in the final Interview guidelines for the TCP and for the expert, which can be seen in Figure 13 and 14 in Appendix 8, respectively. The description in the Appendix also describes why the questions were chosen and how these contribute to testing the initial framework.

The interviews were recorded for analysis of the data afterward. On behalf of the interviewees, the interviews were Dutch spoken. Also, the interviewees had the possibility to choose whether the interview would be held face-to-face or online (Hair et al., 2007). A face-to-face method combined with a semi-structured approach is preferred for this research because it stimulates responses from the interviewee and clarification of questions (Sekaran and Bougie, 2010).

7.4. Data analysis

The ninth and tenth step of the guidelines from Rowley (2012) described how the researcher was able to analyze the data. First, the interview had to be transcribed. These are required to identify patterns in the data and facilitate data analysis (Gioia et al., 2013). The transcriptions were made with the help of Sonix.ai, an automated transcription tool. This tool enabled faster transcription in Dutch for the majority of the interview. Despite this, correcting the transcription afterward was time-consuming but inevitable for making complete and understandable sentences.
The transcriptions were the starting point for coding the interviews. Coding is inherent to qualitative data analysis and accounts for the assignment of themes to certain words or sentences in the interviews (Kvale, 2012). This research made use of a deductive coding approach, which means that the coding scheme is theory-driven. More specifically, directed content analysis coding was used. This method utilizes qualitative data to support and build on a framework from theory (Hsieh & Shannon, 2005). This approach is most suitable for testing the initial framework derived from both SLRs. Therefore, a predefined coding scheme is constructed that

is based on the outcome of SLR 1 and SLR 2, which can be seen in table 11. This coding scheme is based on the information that is expected to retrieve from the interview questions.

Table 11: Predefined coding scheme

1st order codes	2nd order codes	3rd order codes	4th order codes
Extension			
	Application areas		
		Automating	
			Value capture
			Value creation
		Connecting	
			Value capture
			Value creation
		Exploring	
			Value capture
			Value creation
		No digitalization	
			Value capture
			Value creation
		Predicting	
			Value capture
			Value creation
		Simulating	
			Value capture
			Value creation
		Understanding	
			Value capture
			Value creation
	Preparation phases		
	Vision towards Industry 4.0		
Validation			
	General value capture		
	Maturity phases		
		Automating	
			Value capture
			Value creation
		Computerizing	
			Value capture
			Value creation
		Connecting	
			Value capture
			Value creation
		Exploring	
			Value capture
			Value creation
		Integrating	
			Value capture
			Value creation
		No digitalization	
			Value capture
			Value creation
		Predicting	
			Value capture
			Value creation
		Simulating	
			Value capture
			Value creation
		Understanding	
			Value capture
			Value creation
	Order of MM		
		Steps in parallel	
		Subsequent steps	

This coding scheme accounted for a starting point for the coding process. For the text that did not fit the scheme but seemed important to highlight, a new code was created (Hsieh & Shannon, 2005).
The interview questions are divided into two parts, namely extension and validation, so as the coding scheme is. For the extension part, the researcher could exactly list down the paths the TCP described regarding preparation

phases, current phases, and future phases. Also, novel insights can be added to the predefined VCA and VCR factors in each application area and in general.
For the validation part, the interviewees have seen the whole framework. Hence, the researcher could assess if the interviewee agreed with the results from the SLR in their own application area. The interviewee validated the entire initial MM and its order. In addition, the VCA and VCR factors found in theory were assessed on applicability. If so, the category was coded with the statement that the interviewee agreed on the validity. If not, codes were created for the correction(s) under that corresponding code.

The coding process was facilitated with the coding software NVivo, which is a coding program that replaces the "pen and paper" method (Alam, 2021; Rowley, 2012). Within this program, the text was highlighted and added to the initial codes whenever it seemed to fit. The final coding scheme can be found in Appendix 9. The complete interview transcriptions and the complete coding can be retrieved on request.

7.5. Results

This section elaborates upon the results that were retrieved from the interviews. The eleventh and even last step of the guidelines of Rowley (2012) was about writing the results in an understandable manner for the reader. The most important requirement is that the results reflect the research question RQ4. Rowley (2012) states that each sub-theme under the main concept should be identified and elaborated upon with evidence and illustrative quotes.
The findings could be divided into two types: extension and validation. These reflect the interview methods that were described above. In the extension part, the interviewee was asked to reflect upon their road towards Industry 4.0 maturity on the hand of discovering questions, without seeing the framework. That resulted in an overview of a general roadmap from starting point, current status, and vision of that particular company. Additionally, the company explains the VCR and VCA for each of the phases they have completed yet. The insights of all these companies together gave a general overview of the market. The findings in the extension part are summarized and described in the first part of the results section.
After the extension of the framework, validation comes into place. In the validation part, the initial framework is shown and reflected upon by the interviewees. The interviewees reflected on the entire MM as far as their knowledge reached. Here, the interviewee can look beyond their business and reflect on aspects they did not come up with in the first place. This enables a more comprehensive view of the MM. The same counts for the VCR and VCA concepts. However, the interviewee only reflected upon the VCR and VCA concepts that apply to their own application area of MM phases. This step ensured that findings from the literature that were actually valuable, but out of the interviewee's mind, were retained. Also, the validity of the model increased. All quotes that are shown in the result sections are translated from Dutch to English for applicability in the report. Quotes and suggestions are written down as indicated by the interviewees. In this case, the number of the interviewee and their company can be found in brackets. Here, the numbers 1 to 10 account for the amount of interviews in the dataset, where A to H indicate the corresponding companies.

7.5.1. Maturity Model

The initial MM consists of eight aspects that were synthesized by several MMs found in theory. The subsequent phases here are named No digitalization, Computerizing, Connecting, Exploring, Understanding, Predicting, Integrating, Simulating, and Automating.
Table 12 depicts a concept matrix with the phases accordingly that were tested in practice. Here, information is extracted about the TCP's current and past steps in Industry 4.0. The researcher interpreted these in terms of the initial MM and indicated these with a star (*) in the concept matrix. The same is asked about their vision toward Industry 4.0 maturity. Again, the researcher interpreted this and indicated these phases with a plus symbol (+). The exact accounts for the questions in the expert interviews, where the expert is asked how the Industry 4.0 experts experience the road to Industry 4.0 maturity by the TCP.

For the validation part, the researcher showed the initial MM to the TCP and the expert to validate the findings found in the theory. If the company agrees with the inclusion and the order of a phase, the corresponding box is filled in green. If the company agrees with the inclusion, but proposes a different order, the box is filled in yellow. In case the company does not agree with the inclusion of a certain phase, the box is filled in red. Novel phases mentioned by the interviewees that were initially not included in the initial MM are noted down in red.

Table 12: Concept matrix of all MM phases in theory, and tested in practice

	Identified by companies										
	Score theory	A	B	C	D	E	F	G	H	**Score interviews**	**Total**
Extension phase with initial MM											
No digitalization	**7**					*			*	**2**	**9**
Computerizing	**15**	*	*	*		*			*	**5**	**20**
Connecting	**7**	*	*	*	*	*	*	*	*	**8**	**15**
Exploring	**14**	*	*			*		*	*	**5**	**19**
Understanding	**16**	*	+	*		*	+	*	*	**7**	**23**
Prediction	**16**	+					+		*	**3**	**19**
Integrating	**9**									**0**	**9**
Simulating	**5**		*	*	*		*		*	**5**	**10**
Automation	**15**								+	**1**	**16**
Additions to initial MM after extension and validation											
Asset management	**0**								*	**1**	**1**
Unburden the customer	**0**			+						**1**	**1**
Business model change	**4**								*	**1**	**5**

The entire concept matrix is elaborated on per phase in the following sections with illustrative quotes. The first paragraph always describes the insights retrieved from the extension part of the interview, and the second account for the validation part.

7.5.1.1. No digitalization

Extension

The "No digitalization" phase is not part of the Industry 4.0 transition. Therefore, it is not necessarily mentioned by any of the interviewees. All the companies from the data set are applying some Industry 4.0 technologies. Nevertheless, Interviewee 10 (H) states that still most of the TCP has not applied digital technologies in their company and performing traditional maintenance, such as breakdown maintenance or periodical maintenance. The following statement endorses this finding: "*Most are still just doing traditional maintenance. They got calls from the customer or they might do an annual check*." (Interviewee 10).

Validation

After seeing the framework, all interviewees (1 to 10, A to H) validate that the phase "No digitalization" belongs to the MM and is identified as the starting point. Interviewee 10 (H) verified: "*I think it is a good realistic assessment. For example, with "no digitalisation", there is just no knowledge at all of what digitalisation entails. And from that point the awareness begins*."

To summarize, No digitalization is not frequently mentioned by interviewees since it is not an Industry 4.0 phase, but more or less a starting point for most companies. Despite that, it is mentioned as a starting point by two interviewees and multiple times in theory. This makes it a valid starting point for the final framework.

7.5.1.2. Computerizing

Extension

According to Schuh et al. (2020), the computerizing phase is not necessarily part of the Industry 4.0 transition. However, it is a requirement that the company and its machines are prepared so that Industry 4.0 technologies can be performed. Therefore, it serves as a preparation phase for the coming phases. Company A and C mentions that digitalization (or computerization) is a critical requirement before starting with the Exploring phase. Expert Interviewee 1 describes: "*Firstly, many of our customers have had transform their company to get all things digital. This is of course a requirement before you start doing things from industry 4.0 ... If you want to do anything with data at all, your business must at least be digitised.*"

Interviewees 2, 4, and 6 (B, C, E) mention that machines also have to be Industry 4.0 ready, as evidenced by the following two statements: "*For the data aspect and the digital twin, we first had to improve the HMI on our machines ... the HMI was not yet industry 4.0 ready. It did not have the right links to read out data.*" (Interviewee 2, B) and "*Another aspect that comes on forehand is that you are going to make machines capable of connecting. A lot of our machines were just literally a mechanical machine so to speak. I know them actually. They were electrically driven, but there were no other controls on them. So yes, what do you have to read out? And in some cases we did have it, but then it was questionable what value you could really get out of it.*" (Interviewee 6, E).

On the other side, Company C avoided this phase by using only web-based applications. Interviewee 4 (C) explains: "*Digitisation in our industry is not necessary. Almost all of our machines have HMI and PLCs. But I can imagine that this step is necessary for other OEMs. Yes, we have already skipped that step … Look, we expect the customer to have a computer. But what I just said we are not going to install applications with that customer. All our applications, and for me this is a must, must be web-based.*" However, most companies in the dataset uses other concepts as web-based applications, considering that Computerizing is a crucial part for starting the Industry 4.0 transition.

Validation

All interviewees (Interviewees 1 to 10, A to H) validate that Computerizing is a crucial part and evenly in the right position in the model. Interviewee 7, 8, and 9 explicitly reaffirm that computerization on the machine and within the company is a must to enable digital processes. However, Interviewee 4 notes that Computerization is a certainty for customers in their industry, but acknowledge that this may be not the case in other industries.

Summarizing, theory and practice agree with the Computerizing phase as a requirement for further digitalization, despite the possibility to do it web-based. Thus, this phase remains untouched in the final framework.

7.5.1.3. Connecting

Extension

It appeared that all the seven OEMs in the dataset (A, B, C, D, E, F, G) have passed the Connecting phase. The initial framework describes that the Connecting phase is the start of the Industry 4.0 transition and the basis for all the subsequent phases (Fraunhofer & VDMA, 2021; Rockwell, 2014; Schuh et al., 2020; D. R. Sjödin et al., 2018). Interviewees 2, 4, and 6 (B, C, E) have agreed with literature that this phase is a critical requirement before starting with any kind of data logging, starting with the Exploring phase. Moreover, Interviewees 1, 3, and 10 (A, B, H) reveals that this phase is sometimes difficult to overcome according to the security rules in companies. Interviewee 4 (C) adds to this that this step is crucial but sometimes difficult, especially in other countries than the Netherlands: "*A good infrastructure is a must to be able to support the customer. It can be, and we also experience this from time to time, that a network at a customer's site is so inaccessible and secure that the connection to log data or access the machines at all fails. For example, a machine that we install in Asia have very different security and connection requirements from a machine than we install in Europe. It is actually a must to have this preparation in order for us to be able to take steps, because if you don't have a connection to the machine, it becomes very difficult.*"

Validation

All interviewees (Interviewees 1 to 10, A to H) validate that Connecting is a crucial part of the model and is in the right position in the model. Furthermore, Interviewee 7, 8, and 9 (F, G) note that this phase is the basis for the subsequent phases. Nevertheless, Interviewees 1, 2, 3, 5, 6 and 7 (A, B D, E, F) note that remote access, which is a key concept in the Connecting phase, can be executed in parallel with data logging. That is because these companies already performed remote access, before doing the data part, starting with Connecting. The different here is that only internet (VPN) is required to remotely operate a machine, where the rest of the concepts are inherent to a infrastructure for data exchange.

Conclusively, Connecting is the phase that all interviewees have passed in their current Industry 4.0 transition. All of them state that Connecting is the basis for data logging, while some of them use this phase for remote access to their machines. Schuh et al. (2020) note that Connectivity of the machine with VPN is the enabler of remote access, while others say that connectivity is not necessarily a requirement for remote access. Namely, as mentioned by five interviewees, remote access can be done parallel with the data logging phases. Interviewee 5 state that VPN is enough to work with remote access, without the other concepts in the Connecting phase. As remote access and Connecting are in the same phase, these should be split. That is because Connecting consists of key concepts that are required for data logging. Therefore, remote access is considered to be after Computerizing, just as the data logging phases. Thus, remote access can be executed independently from the Connecting, making crucial adjustments to the final framework.

7.5.1.4. Exploring

Extension

Two out of six OEMs in the dataset (A, B) mention that they use the Exploring phase to support their customers, whilst one of them mention that it is also part of the preparation toward other phases (Interviewee 6, E). As described in literature, centralisation of the machine is required for later steps in data logging (Schuh et al., 2020; Xia et al., 2019). Interviewee 6 (E) underlines why it is important to centralise the system when working with data: "*In that sense, it is also a bit of decentralisation. We may have all the functionalities somewhere, but if it was specifically about these machine functionalities, they would not be in one system. So then you actually have to centralise that around that machine first which then often results in decentralisation of your overall system through which you do suddenly get the value within that machine*".

Interviewees 2 and 6 (B, E) explain that the functionalities of this phase is used as a service for customers that only want to know their output. Here, the OEE of the machine is measured to provide basic additional information to the customer, without knowing your machine for optimization (interviewee 6, E). The latter covers the next phase, Understanding. Interviewee 6 (E) mentions that the step toward understanding your machine is still a difficult one: "*There are so many moving parts in a machine. You can't measure everything. So what are you going to measure? Bearings? Every sensor? Temperature? Motor current? As soon as we have a machine connected, then we are going to identify what are the most interesting things to measure … But it is still sometimes quite difficult to know that an individual machine. You have so many moving parts and so many different things that can go wrong. So I think we are still struggling with that, how to deal with that.*"

Validation

All interviewees (Interviewees 1 to 10, A to H) recognize the Exploring phase as to be included in the MM. Interviewees 1, 6, 7, and 8 (A, E, F) underline that Exploring is positioned correctly before the subsequent phases as indicated in the model.

Only Interviewee 9 state that Exploring and Understanding could be executed simultaneously, but remarks that it is more logical to first get familiar with data before actually understanding the machine and the parameters to measure.

Summarizing, theory and interviewees both show that collecting and sharing of relevant outputs is the first step before actually understanding your machine. As a result, this phase remains in the framework as a clear starting point for data logging practices.

7.5.1.5. Understanding

Extension

The key concepts of the Understanding phase is that condition monitoring is applied to machines and that the TCP can thrive optimization with the data. Four out of six OEMs in the dataset are currently practicing this phase (A, E, G). For Companies A and G is this phase still under development, with a vision to have their entire installed base monitored and understanded. In addition, one other OEM (company B) reveals that this phase is one of the future developments that will take place shortly.

Validation

Again, all interviewees (Interviewees 1 to 10, A to H) recognize the Understanding phase in the model. As in the Exploring phase, Interviewees 1, 6, 7, 8, and 9 (A, E, F, G) notify that the Understanding phase is a required step for executing the subsequent phases. However, Interviewee 9 (G) remarks that Exploring and Understanding could be done in parallel, theoretically: "*Then you could do Exploring and Understanding at the same time. Although I do think Exploring normally comes first, before you can really say anything about the machine. That is still a little bit of trial and error.*"

Summarizing, both theory and practice mentions this phase very often, indicating that this phase is in the right place in the model. Some theory and interviewees combine this and previous phase together, while most emphasizing the fact that the Understanding phase is subsequent on the Exploring phase. Thus, the Understanding phase remains as a subsequent phase after Exploring.

7.5.1.6. Predicting

Extension

Only two companies (A, F) are in the beginning phase of Predicting. Both of these OEMs are discovering this phase via interns of the institutions TU Eindhoven and TU Delft. Both are trying to develop an AI or machine learning model for predictive analytics.
From the SLR appeared that Predicting follows from the phases that data is extracted and understanded. This finding is underlined by the expert, Interviewee 10 (H), who says: "*Most interesting to just discuss with customers how many steps they think are needed to get to predictive maintenance, for example. So if they say: we don't do data collection. Then it stops, because you need historical data for predictive maintenance. Seriously, you come across such stories*."

Validation

All interviewees (Interviewee 1 to 10, A to H) verifies that predicting should be included in the model. Furthermore, the phase is in the right position, where Exploring and Understanding is required for executing the Predicting step, explicitly mentioned by Interviewees 1, 6, 7, 8, 9, and 10 (A, E, F, G, H).

In conclusion, both theory and interviewees mention Prediction as a critical phase that comes after the collection and understanding of the data. Thus, Prediction is considered to on the right place in the model.

7.5.1.7. Integrating

Extension

The Integrating phase, which is found in theory to be a requirement for later stages, is never recognized by each of the TCP in the data set. Only Interviewee 10 (H) mentions the key concept of integration as a next step towards Automation. However, he does not see any progress from any TCP in the market: "*Instead of working together to create an ecosystem in which everyone participates and through which everyone simply benefits. Yes, that step still needs to be made. Right now it's mainly just little islands from those OEMs*." (Interviewee 10, H)

Validation

All interviewees (Interviewee 1 to 10, A to H) recognize the Integrating phase in the MM.

Conclusively, none of the employees have recognized the Integration phase as their current application area or vision towards the future. In addition, only nine papers in the theoretical MM mentions this phase in their model. Also, this phase is frequently mentioned together with the Prediction phase, as described in SLR 1. Nevertheless, all interviewees could imagine this phase as an individual phase in the model. This makes that this phase scores nine in total from both theory and practice, which is the lowest score appearing in the model. Due to simplicity and the irrelevance of this phase in practice, it is chosen to exclude this phase from the model.

7.5.1.8. Simulating

Extension

Three companies (B, C, D, F) are already practicing the Simulating phase. However, all four companies describe a different purpose of the so-called Digital Twin, which is a crucial concept in the Simulating phase. Company B uses the Simulating phase to build a visual and dynamic overview of the factory line to show the customer. Also, this company have seen another purpose at another company, namely trial-and-error before commissioning. On the other hand, Interviewee 4 (C) mentions that it can also serve as a visual showroom in combination with augmented reality, while companies D and F are using the technology to identify vulnerabilities while the physical machine is running. Interviewee 1 (A) verifies the abovementioned finding: "*The Digital Twin is used by companies in various ways*". He also note that the Integrating phase is not necessarily required before starting with the Simulating phase, but data is a must. Interviewee 10 (H) emphasizes that most OEMs are misconceiving the term Digital Twin and mention that Digital Twin is more than all the abovementioned aspects. Industry 4.0 expert counters the statements of the OEMs: "*First, it must first be clarified what exactly a Digital Twin means … Sure, all those great stories: A Digital Twin within two weeks and such things. How a Digital Twin must be seen is that just everything really have to be in there. It is mandatory that you have to go to connected machines, to monitoring, to analysis and predicting, before exploiting a Digital Twin … But if they want to start with a digital twin before they have done condition monitoring, I wish them good luck.*" (Interviewee 10, H)

Validation

Interviewees 1, 2, 3, 4, 6, 7, 8, 9, and 10 (A, B, C, E, F, G, H) note that Simulating should be indeed in the model. However, there are variety of conceptions where Simulating should be positioned in the model. As the interviewees already described in the extension phase, four variants of Simulating were identified. Interviewee 10 (H), thinks that Simulating is here in the correct position. Contrastingly, Interviewee 5 (D) mention that this phase can be executed earlier than Predicting, or that the Simulation phase does not belong in the MM at all. Interviewees 5 and 7 (D, F) state that there is even no data or knowledge of the machine necessary to perform Simulations. Interviewee 5 (D) explains that they did simulations before they applied remote access, but with a sidenote that this exception is very specific for robots, especially with ABB robots. Therefore, some aspects of the Simulating phase can be executed in parallel to several phases, depending on the purpose of the Digital Twin.

Conclusively, several companies state that they are using a Digital Twin for many purposes through the timeline of the MM. Nevertheless, the Industry 4.0 expert state that these variants are not actually a Digital Twin. Due to the sparse know-how of the rising Digital Twin and inconsistency of the statements of the OEMs in the dataset, it is chosen to follow the reasoning of the Industry 4.0 expert. Thus, the Simulating phase in its most optimal forms is maintained on the same position in the model.

7.5.1.9. Automating

Extension

Lastly, none of the OEMs have yet reached the Automating phase. From the SLR appeared that Automating is the last phase of Industry 4.0 maturity. The road to maturity is set out by Interviewee 10 (H), where Automating is the last phase: "*You first have to go to connected machines, to monitoring, to analytics and predict, and only then you reach digital twin. Then you have to go from asset management to self-optimising systems*.". So automating is recognised by Interviewee 10, but have not seen this in the Netherlands yet. Thus, it is not common for this to happen within a short period. Interviewee 10 (H) explains: "*Those self-optimising factories, I haven't been to such factories here in the Netherlands myself. That is because they just can't do that cost-benefit analysis. Then, digitalisation is always the losing factor.*".

Validation
All interviewees (Interviewee 1 to 10, A to H) recognize the Automation phase and verify that this is the end-point of the MM. However, Interviewee 10 (H) illustrates that Automating is far for TCP, but not unreachable: "*I think the MM is true. I would say, though, that automation is still very far away for SME OEMs. But of course, you don't know what the future looks like. We thought a few years ago that AI would not be feasible either*."

Conclusively, interviewees and theory agree with the Automating phase as the end-point of the MM.

7.5.1.10. Other phases

Extension
This subsection describes other MM phases that were mentioned in the extension part of the interview, that can not be linked to any of the found phases in the initial MM. Firstly, Interviewee 10 mentioned "asset management" as one of the steps between Simulating and Automating. Asset management is not mentioned by any of the papers in the SLR.
Secondly, Interviewee 3 described that their vision is to unburden the customer.

Due to the fact that these MM aspects are not mentioned in theory and it is mentioned by each interviewee each, the suggestions are not included in the final framework. More specifically, unburden the customer is a vague term that is already integrated in each of the phases to some extent. It also makes it hard to quantify whenever the customer is unburdened or not.

Validation
After seeing the initial framework by the participants, Interviewee 10 came up with an extra possible missing part as an end-phase of the MM: Business model change. Business model change is also mentioned several times by researchers in the SLR (Gökalp et al., 2017; Leyh et al., 2016; PWC, 2016; Weber et al., 2017).

However, business model change is not frequently mentioned enough in theory to be included in the initial MM in the first place. Moreover, business model change is not found on a fixed position in the MM, indicating that researchers do not agree on when business model change takes place. Thereby, this research focuses explicitly on how OEMs can derive a business model in every phase of the MM. This is in contrast with the statement that Business model change is a specific individual phase somewhere in the model. Thus, this suggestion for an end-point of the MM is not included.

7.5.2. VCR and VCA

This section elaborates on the VCR and VCA concepts that were found in the SLR. It describes in which way TCP could create and capture value for themselves an the end-user in the disciplines maintenance and operations. The extension part's goals is to extract novel insights of the TCP's current state of the market in terms of VCR and VCA concepts used in practice. Accordingly, question 6, 7, and 8 of Interview 1 retrieves information from the interviewee about the benefits experienced, the revenue generated and a business case described, respectively. Here, Questions 5, 6, and 7 in Interview 2 are serving the same purpose as abovementioned questions, focusing on experts. The second paragraph of the subsections validates the VCR and VCA concepts that were shown to the interviewees. In this case, question 12 and 13 from Interview 1 assessed the theoretical VCR and VCA concepts in the TCP's area of application. The same count for questions 10 and 11 from Interview 2.

To get an overview of these theoretical concepts that were chosen to test in practice, the concept matrix with VCA concepts from SLR 2 was enlarged. It shows the number of times a VCA concepts is mentioned in theory, even as the concepts that were mentioned by the companies in the dataset. Novel insights from the interviewee that were earlier identified in theory, are noted down in black. Moreover, the novel insights that were mentioned by the interviewees but not in theory, are noted down in red.
Also, the validation part is executed to validate the insights that were not initially mentioned by the interviewees. This part ensured that the interviewees can assess if the VCA concepts in a particular phase are valid or explicitly not. If the company agreed with the inclusion of the VCA concepts within that phase, the corresponding box is filled green. If the company disagreed with a certain VCA method, the box is filled red. The company only validates the VCA concepts within the phase they have actually passed or have clear ideas or vision towards a certain phase. As described in previous section, a star (*) is noted down if the company have passed the MM phase or it is its current phase, while a plus sign (+) means that the particular phase is a future development and/or vision of the company.
The entire concept matrix is elaborated on per category and per phase in the following sections. The concept matrix is shown in table 13.

All VCA concepts that were retrieved from literature can be seen in the initial MM. This model will be extended or downsized, as well as validated from the interviews, with the help of standards and logical reasoning. Firstly, VCA concepts are included in the model that were mentioned both in theory and in practice. Secondly, VCA concepts mentioned more than once in theory, were also included in the model. Thirdly, VCA concepts that were mentioned by interviewees are included, based on the amount of times a VCA method is mentioned compared to the number of companies that participate in that particular phase, as well as the logical reasoning of the interviewees.
The inclusion or exclusion of a VCA concepts will also depend on the validation of these concepts by the interviewees.

Table 13: Concept matrix of all VCA concepts in theory, and tested in practice

		Identified by companies									
	Score theory	A	B	C	D	E	F	G	H	**Score Interviws**	**Total**
No digitalization						*			*		
SLA	**1**					X			X	**2**	**3**
Pay-per-repair	**0**								X	**1**	**1**
Connecting		*	*	*	*	*	*	*	*		
Error reduction costs	**1**	X	X		X	X	X	X		**6**	**7**
(Better) SLA	**0**	X		X		X		X		**4**	**4**
Spare part management	**0**				X					**1**	**1**
Exploring		*	*			*		*	*		
Freemium	**1**					X				**2**	**2**
Consumables-as-a-service	**0**	X						X		**2**	**2**
Software -and hardware sale	**0**					X				**1**	**1**
Understanding		*	+	*		*	+	*	*		
(Better) SLA	**1**	X					X	X		**3**	**4**
Performance-based	**3**									**0**	**3**
Subscription (basis)	**1**					X				**1**	**1**
Processing time cost reduction	**1**	X								**1**	**2**
Cost reduction	**1**									**0**	**1**
Pay-per-use	**2**									**0**	**2**
Outcome-based	**1**									**0**	**1**
Additional services or upgrades	**1**			X				X		**2**	**3**
Spare part management	**1**		X	X				X		**3**	**4**
Project-based	**0**	X								**1**	**1**
Freemium	**0**					X				**1**	**1**
Predicting		+					+		*		
(Better) SLA	**2**								X	**1**	**3**
Performance-based	**3**									**0**	**3**
Subscription (recurring)	**2**									**0**	**2**
Lease	**1**									**0**	**1**
Cost reduction	**1**									**0**	**1**
Preventive maintenance contract	**1**									**0**	**1**
Pay-per-use	**3**									**0**	**3**
Outcome-based	**1**									**0**	**1**
Additional services or upgrades	**1**									**0**	**1**
Spare part management	**3**									**0**	**3**
Higher machine sale	**0**						X			**1**	**1**
Simulating			*	*	*		*		*		
Performance-based	**2**									**0**	**2**
Prescriptive maintenance contract	**1**									**0**	**1**
Pay-per-use	**2**									**0**	**2**
Outcome-based	**1**									**0**	**1**
Additional services or upgrades	**2**		X				X			**2**	**4**
(Better) SLA	**0**								X	**1**	**1**
Cost reduction	**0**		X		X					**2**	**2**
Automation									+		
Performance-based	**2**									**0**	**2**
Customized contractual agreement	**1**									**0**	**1**
Pay-per-use	**2**									**0**	**2**
Outcome-based	**1**									**0**	**1**
XaaS	**0**								X	**1**	**1**

All the VCR concepts that were included in the initial framework were also extended and tested with the interviewees the same way as the VCA concepts. Therefore, a concept matrix was derived, which can be seen in table 14. These concepts can be very diverse and specific for each OEM and industry. The following sections elaborate on all the VCR concepts mentioned by the interviewees and to which extent it has overlap with theory. The number of times a concept is mentioned compared to the number of companies that participate in that particular phase, determines whether to include a novel concept. Further explanation for inclusion or exclusion was be provided in the next sections. The validation part decides on the remaining findings from the literature in the final framework.

Table 14: Concept matrix of all VCR concepts in theory, and tested in practice

		Identified by companies									
	Score theory	A	B	C	D	E	F	G	H	**Score interviews**	**Total**
No digitalization						*			*		
Unstructured logistic processes	1									0	1
Spare parts fully used	1									0	1
High downtime	1									0	1
Damaged asset	1									0	1
Minimized downtime	1									0	1
Excessive maintenance	1									0	1
Waste in spare parts	1									0	1
Connecting		*	*	*	*	*	*	*	*		
Faster support	1	X	X		X	X		X		5	6
Strengthened relationship between OEM and service provider	1									0	1
More secure network	1									0	1
Redcued manpower	0				X	X	X	X		4	4
Overcome languague barriers	0			X						1	1
Exploring		*	*			*		*	*		
Higher transparancy on OEE	2	X								1	3
Quicker and better delivery data prediction	1									0	1
Better production planning	2									0	2
Improved utilization of machines	1									0	1
Faster throughput times	1									0	1
Higher customer satisfaction	1									0	1
Visibility into energy standards	0	X								0	0
Understanding		*	+	*		*	+	*	*		
Up to 70% reduced breakdowns	2	X						X		2	4
Up to 50% reduced downtime	1	X						X		2	3
Up to 50% reduced unplanned outages	1									0	1
Up to 25% reduced maintenance costs	4	X				X				2	6
Up to 12% reduced scheduled repairs	1									0	1
Reduced maintenance hours from 50% to 70%	1									0	1
Improved operational performance	3	X		X		X	X			4	7
Increased productivity	1									0	1
Increased product quality	1			X						1	2
Increased efficiency	1			X						1	2
Preventing waste material	1									0	1
Reduced energy emissions up to 50%	0							X		1	1
Responsibilities can be allocated more clearly	0						X			1	1
Predicting		+					+		*		
+9% to 20% uptime by optimizing repair and maintenance schedules	3						X			1	4
+20% to 50% reduced efforts in maintenance planning	1									0	1
5% to 12% reduced maintenance costs	1									0	1
From 4% to 5% productivity	2									0	2
-50% rejected products	2						X			1	3
5% to 12% cost reductions in operations and material expenditures	3						X			1	4
36% energy savings	1									0	1
-14% safety, environment, health and quality risks	1									0	1
20% lifetime extension of machine	1									0	1
Reduced inventory levels from 120 to 82 days	1									0	1
50% reduced lead times	1									0	1
80% to 95% on-time deliveries	1									0	1
82% to 98% customer delivery performance	1									0	1
Simulating			*	*	*		*		*		
Supporting engineers in diagnosing and troubleshooting	1									0	1
Visual help and training for operators	1		X				X			2	3
Easier identification of vulnerabilities	2				X	X				2	4
Reduction of inconsistencies for more efficient processes	1									0	1
Increased optimization possibilities	1		X							1	2
Minimizing manual work/ reduced manpower	1									1	2
Increased product quality	1									1	2
Eliminated production loss	2									1	3
Doing things the first time right	0		X	X	X		X		X	5	5
Better overview of the machine components	0				X					1	1
Automation									+		
Warnings solved that are overlooked by operators	1									0	1
Reduced manpower	3									0	3
Quick adaptation	2									0	2
Reduced risk	2									0	2
Reduction of deployment costs with customized offerings	1									0	1
Continuously improving	1									0	1
Value adding for the whole ecosystem	1									0	1
Lower costs and ecological footprint	1									0	1

The next section follows the same structure as in SLR 2. The first part of the section always starts with the extension of the VCR concepts, followed by the second section VCA. The second part focuses on the validation of the theory.

7.5.2.1. Maintenance

Breakdown maintenance

Extension
Breakdown maintenance is not part of the Industry 4.0 revolution. Consequently, no TCP mentioned breakdown maintenance, since every TCP have applied at least one Industry 4.0 aspect. Hence, only the Industry 4.0 expert identified the breakdown maintenance. Namely, interviewee 10 described that most of their customers, which are TCP, are still performing breakdown maintenance. He stated that TCP's in this phase mostly using a pay-per-repair or a SLA as VCA method. Thus, pay-per-repair is added as a way of capturing value with breakdown maintenance. No novel insights regarding VCR are identified.

Validation
Nevertheless, al interviewees (Interviewee 1 to 10) have approved the VCR and VCA concepts found in theory. Additionally, new information emerged that had not been thought of on forehand. Interviewee 7 verifies the insights of Interviewee 10, that their company used a SLA before applying Industry 4.0 technologies.

Periodical maintenance

Extension
Identically as in the previous VCR and VCA concepts, only interviewee 10 identified on the periodical maintenance phase. However, no VCR or VCA aspects are described here.

Validation
After seeing the framework, all interviewees (Interviewee 1 to 10) underline this phase and recognizes the according VCR and VCA concepts.

Remote maintenance

Extension
As described before, all TCP in the dataset are applying remote maintenance. Here, OEMs can connect to their machines remotely to do maintenance with faster support. Five companies (A, B, D, E, G) have also experienced faster support, as identified in the theory. As a result, OEMs can minimize downtime, mentioned by companies A, C, and D. The latter is another problem that is solved with connected machines. Namely, company D, E, F and G can now maintain the same amount of machines with reduced manpower or handle a rising amount of machine with the same manpower. Interviewee 6 illustrates: "*Now we keep the specialist closer to home who can look at several things at once and give advice. So there is also a rationale behind the idea that we as a company should be able to maintain the same amount of machines, or perhaps an increasing amount of machines, with less knowledge.*". Interviewee 5 handles a higher amount of machines with one service engineer: *My colleague left overworked some time ago. He had about 100 machines under his management and so he just couldn't manage that anymore. I now have 200 and I have time to spare. It saves so much stress and time if you can do it right the first time*." Thus, these two ways of creating value is added to the final framework, even though it is not recognized by theory. Lastly, one company (C) have overcome misconceptions regarding language when support is executed online. This finding is only mentioned one time, meaning that it is not relevant for the final model.

At first, value is captured since support becomes cheaper (Company A, B, D, E, F, G). Hence, costs are decreased for themselves or the end-user, depending on the cost structure in place. Interviewees 1, 6, 7, and 8 provide an example where the costs of a remote access is already paid back by the reduced extra costs of the

engineer and its flight. This is in line with the formula in theory. However, it is slightly adjusted since it did not account for the costs of the airflight.
Four OEMs (A, C, E, G) have constructed a better SLA than before. Interviewee 8 illustrates: "*So that's in that service support agreement then the customer then pays for. And the fact that we can do that in that way, that we can do that remote access or remote diagnostics, that is the value they are paying for*." Interviewee 5 contradicts this statement, noting that whenever remote access is integrated in a SLA, the end-user is going to call for everything. Moreover, the end-user is losing their responsibility for maintaining their machine. Nevertheless, due to the high number of companies using this to conclude a better SLA, it is included into the model. Consequently, this OEM (D) captured value by selling spare parts, because the end user is more likely to approve that OEM may supply spare parts when they have called the OEM. Since it is not mentioned by theory and one time by an interviewee, it does not seem to be a relevant way of capturing value in this phase.

Validation
All companies have underlined the VCR and VCA as described in the framework. Interviewees 1, 2, and 5 specifically mention again that SLA is used frequently here.

Proactive maintenance

Extension
Preventive maintenance ensures that problems could be identified before breakdown. This reduces breakdowns and downtime, according to theory. These two advantages is recognized by two out of four OEMs (A, G) that performing the Understanding phase. More specifically, Interviewee 8 mentions that breakdowns can be reduced up to 50%. As a result, maintenance costs also reduces. This is experienced by OEMs A and E.
As in previous phase, more machines can be maintained by the service engineer, resulting is reduced manpower. This is in line with the finding from Company E and from theory that less hours are spend on maintenance, resulting is less manpower per machine. Another point that is not identified in theory but mentioned by Interviewee 7 (F), is that responsibilities can be allocated more clearly. The OEM can identify the cause of the problem and negotiate with the end-user about responsibilities and contractual guarantees, such as in a SLA described below. This finding is not considered in the final framework, due to lack of evidence.

The reduced maintenance costs and the process reduction formula described in the VCR part directly results in profits. This is identified by Company A as one way of capturing value.
Other literature describes that the value created can be Captured in an upgraded SLA. Company A and F, and G also upgraded their SLA in this phase. Company G identified four types of SLAs in their company. Here, more functionality is integrated subsequently by every upgrade of the SLA. Interviewee 8 (G) elaborates on the first and fourth SLA: "*We have four types of SLAs. ... is the lowest package; then they can always call and have access to the portal. This is the self-supporting customer. And that that always builds up to the highest package. Those customers are completely performance-driven. They just do not want to have any downtime, if they are idle they want to be helped as quickly as possible and they invest a lot in preventive maintenance. So we just want to make sure those machines are always running. That is why we do preventive maintenance on all machines. The service engineer visits them four or six times a year. We make whole analyses about what needs to be done and what is coming up for maintenance. So we look at that every day, all the reports that are on that machine and give advice to that customer. And the customer does not have pay for that separately, it's all included in the total sum. Because if we were to sell it separately, well then maybe a lot of customers would say; well I don't want it or I don't want to pay that much for it. And the rollout of that SLA is just super successful the first year. And I think we are also learning more and more about what we can then do with that data*."
Additionally, Company C and G uses the data to increased their revenues by selling more spare parts before these break down, where Company B names this as their vision for the future. This way of VCA is also identified in this phase.
Company A uses a project-based business model. Here, dashboards are created for a one-time fee, where recurring hosting costs are negligible. These projects are mainly applicable to end-users where downtime had disastrous consequences regarding production losses.

Company E uses freemium models to convince the customer with a limited free trial, following with a subscription if the end-user is interested in full functionalities. This is not necessarily underlined by theory in this phase. These ways of VCA seems industry specific and not necessarily relevant for the final model, indicated by the number of times these are mentioned.

Validation
All interviewees that are participating in the Understanding phase (Interviewee 1, 4, 5, 8, 9) have recognized the value that can be created and captured with preventive maintenance. All of them underline the statistics listed in the framework, but do not know their companies' statistics. Interviewee 4 explains: "*Look, the statistics for that industry will be correct I guess. I do not know exactly how it is in our industry. Breakdowns do indeed shoot down when proper maintenance is done. What percentage that is, I really do not dare to say. I do not have that data at hand and, to be honest, I have not really kept track of it either*"

Preventive maintenance

Extension
As described before, only two Companies (A, F) are in an earlier phase of Predicting. Therefore, the TCP have not experienced full potential of this planned maintenance. However, Company F would like to use to Predicting to improve their maintenance schedules, which is also identified in the theory.

Two companies have mentioned two ways of capturing value which are not identified in theory for this particular phase. Namely, Interviewee 7 of Company F thinks that predictive maintenance could lead to a higher amount of machine sale. This finding is not included in the final framework, since it is mostly applicable to the functionalities of their machines, namely robots. Interviewee 10 sees that TCPs integrate predictive maintenance in their SLR. Therefore, the construction of a better SLA is extended to the Predicting phase.

Validation
Despite the lack of experience in this field, all companies in this phase (A, F, H) validate the findings that are found in theory.

Visual maintenance

Extension
From theory appeared that simulations make it possible to identify vulnerabilities more easier. Company D and F also recognizes this way of creating value. Interviewee 5 describes how Company D does this: "*We even do troubleshooting here with simulation models… If there is a malfunction at a customer, I put their data in the digital twin and find out what the problem is. And that is so fast, when a customer has a strange malfunction and you put that into a digital twin, you can find out what's going on within half an hour without having to go there and search for hours*." Interviewee 5 (D) also state that these simulation models give a better overview of the components in the machine, which is not directly identified in literature.

Interviewee 10 (H) state a better SLA can be derived with simulations model. The construction of the SLA mentioned by the Industry 4.0 expert is in line with the finding from theory that a prescriptive maintenance contract can be constructed, where OEMs can give recommendations on setting parameters to let the machine run optimally. Therefore, the SLA that is used in this phase is prescriptive, which is more advanced as the preventive maintenance contract in previous phase.
However, Company D does not use SLAs in their business. So, without using SLAs, revenue per order increases. Interviewee 5 (D) explains: "*With simulation models, we do skip the hassle, and therefore you can earn more revenue. So revenue per order goes up, but orders get smaller … Theoretically this is crazy because you make less money. Normally you say that you are better off by visiting the customer, but that's actually not true in practice. In the end, you're better off just doing ten little jobs a day with smaller revenue, than visiting a customer once, for example. Here you have all the hassle afterwards and the customer that thinks that it is an expensive invoice*." Company B underline this finding that costs and manpower can be reduced significantly,

leading to direct profits. This findings is not directly identified in the theory, but follows from the theoretical finding that it is easier to identify vulnerabilities. Thus, cost reduction is included in the final framework.

Validation
All interviewees (2, 3, 4, 5, 7, 10) from companies that practices this phase have validated the VCR and VCA concepts retrieved from literature.

Automated maintenance

Extension
No companies are yet on the level of the Automating phase. Therefore, no novel contributions could be made regarding VCR and VCA for automated maintenance.

Validation
Due to the reasoning above, only the expert could, and have, validated the VCR and VCA concepts found in theory.

7.5.2.2. Operations

Transparency provider

Extension
This phase ensures that the OEE or KPIs of the machine are monitored and shared between the right people. Consequently, transparency into the production process is obtained for the end-user, found in theory. This finding is also mentioned by Company A.

As a result, OEMs are now able to get transparency on the input and output of a machine in the field. Companies A and G recognizes this opportunity to sell consumables at the right point in time, which increases revenues. Interviewee 1 (A) illustrates: "*We are now able to send plastics to the customer, ensuring that they do not run out of stock.*" This is not directly found in literature and therefore added to the final framework.
Both theory and Company E describes that a Freemium business model is the way to convince the customer to pay for OEE data of the machine. After the trial period, a subscription is applied. Interviewee 6 (E) explains their payment structure: "*And once we start measuring something of performance, we put that into a subscription. A certain amount per month, depending on the value. So if we generate a lot of value, the amount is higher. And what we achieve with that is that the moment we deliver that machine and it chooses connectivity, it gets a piece of insight for free. Usually we put something in there that make him curious enough so that he wants more of it. And if we have that, it gives us as a company total insight into the system … So if you buy a machine, then you get a free piece of OEE logging. And the moment you say: I want to have that part too, then you get a subscription*.". However, he mentions that it is an requirement that the OEM is actively involved in monitoring the data, to identify opportunities for improvements. Otherwise, the data will be neglected. This was seen before, when Company E sold their OEE based of the hardware -and software costs. Therefore, this manner of capturing value in this phase is not included into the final framework.
Validation
All four OEMs that have acted as a transparency provider have validated all the findings that were found in theory. Nevertheless, Company A also remarked that monitoring OEE is eagerly wanted to some of their customers for adhering to sustainability guidelines. This finding is applied to the model, since monitoring of energy levels are considered important these days, due to the climate goals and energy crisis.

Machine optimization

Extension
Increased operational performance is one of the key advantages of the Understanding. This is frequently found is literature and also experienced by Companies A, C, E, F. Operational performance can include various aspects. Company C mentions two operational improvements that were made and also found in theory: increased machine efficiency and increased product quality. Interviewee 4 (C) explains how product quality can

be enhanced by monitoring relevant parameters: "*Preparing bread is highly dependent on the climate in the oven. I have to make sure my oven is in a perfect condition to bake the product. And then when you talk about the moisture and temperature care piece with a product, you can optimise that. That is important. Humidity is very sensitive, temperature less so. I can control that better now. But I can not always control humidity. But you can ensure that the regulations to keep moisture at the right level are optimised. Is definitely a point we are working on*." Also, Company G mentions that reduction of emissions is a highly popular aspect in the last year, relating to the inflating gas prices and net zero goals. Interviewee 9 (G) shows that data monitoring can ensure that up to -50% gas or electricity reduction. This finding is not specifically mentioned by theory, but is in line with the increased operational performance. Also, reduction of emissions is a hot topic since the energy inflation crisis. Thus, this finding is included in the final framework.

Interviewee 9 (G) describes that such improvements are easily pay itself back by providing additional services: "*Here the energy consumption was 20,000 kilowatt hours per week approximately. And after we made an adjustment, it was only 12,000 kilowatt hours per week. So we sell this as a separate service. But that comes with an ROI that we can determine based on data. So we can estimate that return in advance based on the estimated reduction and the kilowatt-hour price. This recommendation can cost as much as 80,000 euros. That's a payback period of 1.5 years and this service sells itself.*"
The value that is created with other improvements can also be Captured by additional services, according to the literature. Companies C and G also mentions additional services as the way to VCA value. Interviewee 8 (G) illustrates how business can be derived with extra services: "*So we really try to use these kinds of dashboards for business. An account manager goes out with the dashboard to the customer and explains that he sees a lot of problems in changing paper rolls, indicating that paper rolls are stuck. A solution can be to switch the disk. Yeah, extra business does originate from this*."
Interviewee 4 (C) handles the same approach: "*If the customer does not need help, but wants an extension based on the data, this is an extra service. For example, they want to change the controls of the output of a PLC, or changes in the HMI. That are just customer-specific tasks, and just paid on hours. That's how we differentiate*."
The same value can also be Captured with a subscription, where these additional services described above are Captured in a contract on a recurring bases. This is identified by theory and Company E. Interviewee 6 explains that optimization in a subscription brings some inconsistencies in creating value: "*I think maybe our big challenge is to determine what the value is that you deliver. With some customers that value is huge because they are already at such a bad level and you bring them all the way up. And some customers who were already at pretty high levels and you bring those up a little higher. Then, of course, you are not going to say they are bad and therefore charge more per month. That's still the difficulty. You also have to be careful not to apply a subscription per machine to a company with 200 machines, so that the price becomes very high. So we also looked at subscription models on a total system. So, for instance, you are a high-end customer, so you just pay a fixed amount per month per plant.*". Moreover, the OEM included in their terms and conditions that the data can also be used by the OEM, whereby it can be used as optimization for further machine designs.

Validation
All companies participating in this phase (A, C, E, F) have validated the VCR and VCA that were found in theory. Only, Interviewee 8 (G) remarked that he misses sustainability enhancement, which is one of the most important concepts that Company G experience in this phase. This finding is already included in the final framework as mentioned in the paragraph above.

Predictive production

Extension
As described before, limited amount of Companies (A, F, H) have experienced full potential of the performance enhancement in this phase. Nevertheless, the purpose of the pilot within this phase was to reduce the amount of failed products and therefore reduce costs (Company F). This is also identified as a key aspect in theory.

Company F state the value created can be captured by means of a higher product price, which is not directly identified in theory. As described before, it seems very specific for the functionalities of the machine. Hence, this is not included in the final framework.

Validation
Both Companies (A, G) involved in the Predicting phase, even as the expert (H), have validated the VCR and VCA concepts as described in theory.

Scenario optimization

Extension
A frequently mentioned aspect (Company B, C, D, F, H), that is not identified by theory, is that OEMs can do simulations to do things the first time right. Hence, this phase is advantageous for the development and commissioning of the machine by reducing the installation time on location (Company B). Namely, simulations can help to prepare, test and debug a virtual model before it is even build. Interviewee 4 (C) explains how this is done: "*So by means of simulations: I look at how should I set up that line or how do I prevent empty positions in my production? Yes, well, that is a very broad concept. But our director is already saying that we should be able to test a PLC programme on a simulation shortly*.". Expert Interviewee 10 goes even further by describing the all-in solution regarding simulation: "*Instead of first developing a machine, building, installing, and testing, you are talking in years … With simulation you can just build whole new factories with everything we just discussed about the digital twin. You literally build your whole plant in a software programme, to do all the simulations. You can even calculate how much manual work goes into it, you see literally see people walking, you see them lugging, you see them grabbing things, for example. Based on that, you get improvements like if they have to grab something from a height of 1.20m, how much that can do per hour or how many problems that can cause. It really goes super deep into the smallest details and that's actually where we want to go.*". Since almost all participants in this phase agree with this benefit, it is included in the model.
Also, the machine design can be optimized in operation even further by putting the retrieved data back into the simulation to identify over dimensionalities or wrong choices, as indicated by Interviewee 2 (B). This finding validates the finding in theory.
Lastly, Companies B and F, as well as theory, mentions that a simulation model makes it possible to train operators on every scenario that can happen. This could enhance performance in the future.

As a result, Companies B and F see a possibility to VCA this created value by providing extra services such as training possibilities to the end-user.
On the other hand, Company B and C also use simulation model to convince the customer, while serving as a sales tool. Interviewee 8 (B) illustrates: "*We use this primarily as a sales tool … we can build our machines as modules that we can place interactively in a layout as a kind of plug-and-play, to start up a communication and dialogue with a customer … Here you can show; if your filler goes a bit harder, there will be a bottleneck here, but we can solve that bottleneck in no time, we've already thought of that. We can offer that … Yes, we hope this will get more customers interested, so higher sales of machines in the end*.". This finding aligns with the earlier statements that a factory can be build on forehand. So, this method is included in the final framework.

Validation
Next to the extensions described above, all Interviewees (2, 3, 4, 5, 8, 9, 10) also validated the already found VCR and VCA concepts from literature.

Operational excellence

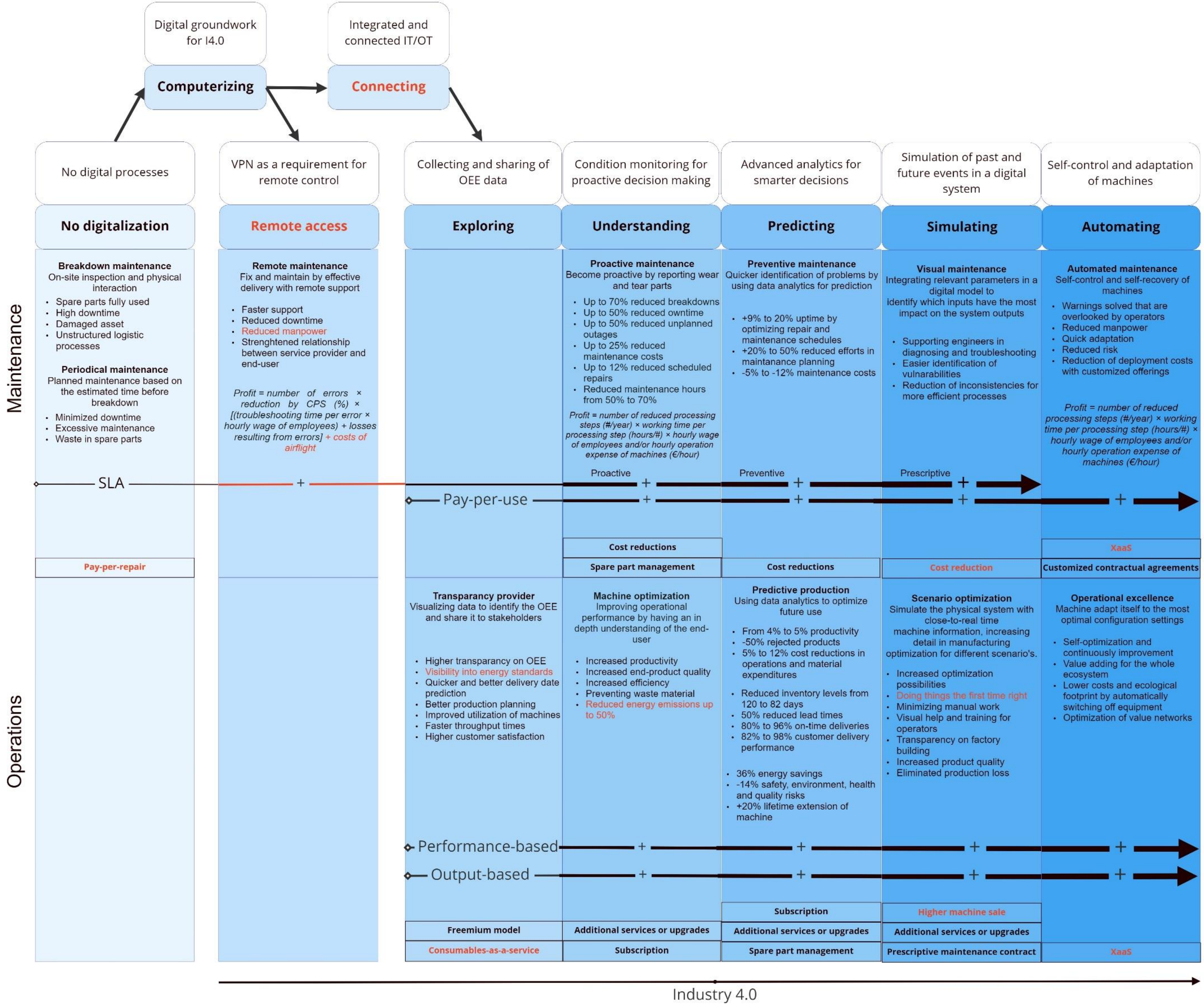
Extension
As described before, no companies are yet participating on this level. However, the identification of self-optimizing systems mentioned by Interviewee 10 is aligned with the VCR found in theory.

Interviewee 10 also state that the end-point of all the business models should be XaaS, the so called everything-as-a-service. As this way of capturing value is identified by the Industry 4.0 expert and widely used known in literature, it is included as the final business model. With XaaS, every service-oriented business model comes together, resulting that everything is sold as a service.

Validation
The expert (interviewee 10) is the only participant validating this phase, indicating that the VCR and VCA concepts found in literature seem correct.

7.6. Present (Final framework)

The results that are described in the previous section are integrated into the initial framework, resulting in the final framework. The red markings are novel insights, which indicate adjustments made compared to the initial framework. The remaining part of the framework is tested and validated. As a result, the final framework is extended and validated with the TCP, making it applicable for SMEs. The final framework can be seen in Figure 13.



Digital groundwork for I4.0
Integrated and connected IT/OT
Computerizing
Connecting
No digital processes
VPN as a requirement for remote control
Collecting and sharing of OEE data
Condition monitoring for proactive decision making
Advanced analytics for smarter decisions
Simulation of past and future events in a digital system
Self-control and adaptation of machines
No digitalization
Remote access
Exploring
Understanding
Predicting
Simulating
Automating
Maintenance
Breakdown maintenance
On-site inspection and physical interaction
Spare parts fully used
High downtime
Damaged asset
Unstructured logistic processes
Periodical maintenance
Planned maintenance based on the estimated time before breakdown
Minimized downtime
Excessive maintenance
Waste in spare parts
Remote maintenance
Fix and maintain by effective delivery with remote support
Faster support
Reduced downtime
Reduced manpower
Strenghtened relationship between service provider and end-user
Profit = number of errors × reduction by CPS (%) × [(troubleshooting time per error × hourly wage of employees) + losses resulting from errors] + costs of airflight
Proactive maintenance
Become proactive by reporting wear and tear parts
Up to 70% reduced breakdowns
Up to 50% reduced owntime
Up to 50% reduced unplanned outages
Up to 25% reduced maintenance costs
Up to 12% reduced scheduled repairs
Reduced maintenance hours from 50% to 70%
Profit = number of reduced processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)
Preventive maintenance
Quicker identification of problems by using data analytics for prediction
+9% to 20% uptime by optimizing repair and maintenance schedules
+20% to 50% reduced efforts in maintanance planning
-5% to -12% maintenance costs
Visual maintenance
Integrating relevant parameters in a digital model to identify which inputs have the most impact on the system outputs
Supporting engineers in diagnosing and troubleshooting
Easier identification of vulnarabilities
Reduction of inconsistencies for more efficient processes
Automated maintenance
Self-control and self-recovery of machines
Warnings solved that are overlooked by operators
Reduced manpower
Quick adaptation
Reduced risk
Reduction of deployment costs with customized offerings
Profit = number of reduced processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour)
SLA
Proactive
Preventive
Prescriptive
Pay-per-use
Pay-per-repair
Cost reductions
Spare part management
Cost reductions
XaaS
Cost reduction
Customized contractual agreements
Operations
Transparancy provider
Visualizing data to identify the OEE and share it to stakeholders
Higher transparancy on OEE
Visibility into energy standards
Quicker and better delivery date prediction
Better production planning
Improved utilization of machines
Faster throughput times
Higher customer satisfaction
Machine optimization
Improving operational performance by having an in depth understanding of the end-user
Increased productivity
Increased end-product quality
Increased efficiency
Preventing waste material
Reduced energy emissions up to 50%
Predictive production
Using data analytics to optimize future use
From 4% to 5% productivity
-50% rejected products
5% to 12% cost reductions in operations and material expenditures
Reduced inventory levels from 120 to 82 days
50% reduced lead times
80% to 96% on-time deliveries
82% to 98% customer delivery performance
36% energy savings
-14% safety, environment, health and quality risks
+20% lifetime extension of machine
Scenario optimization
Simulate the physical system with close-to-real time machine information, increasing detail in manufacturing optimization for different scenario's.
Increased optimization possibilities
Doing things the first time right
Minimizing manual work
Visual help and training for operators
Transparency on factory building
Increased product quality
Eliminated production loss
Operational excellence
Machine adapt itself to the most optimal configuration settings
Self-optimization and continuously improvement
Value adding for the whole ecosystem
Lower costs and ecological footprint by automatically switching off equipment
Optimization of value networks
Performance-based
Output-based
Subscription
Higher machine sale
Freemium model
Additional services or upgrades
Additional services or upgrades
Additional services or upgrades
Consumables-as-a-service
Subscription
Spare part management
Prescriptive maintenance contract
XaaS
Industry 4.0

Figure 9: Final framework

8. Discussion

This section discusses the findings that were found in literature and practice, next to the implications that were already made in the result section. It provides an opportunity to interpret and explain the findings of the study in relation to the research gaps. It gives insight into the broader implications of the research, including its relevance in the field, its limitations, and potential for future research. Lastly, a conclusion is derived that summarizes and elaborates on the main findings of this study.

8.1. Theoretical implications

8.1.1. Findings from literature

8.1.1.1. Maturity model

At the start of the research, there was a need for a MM that could serve as the basis for VCR and VCA concepts. First, a critical reflection of the existing body of literature on this topic have led to the conclusion that no MM is suitable to serve as the basis for business models. Hence, several papers that were relevant to this research were addressed and analyzed. The phases, and more specifically, the key aspects in this phase, were analyzed and synthesized to derive a MM that is suitable for this research. That is, technological aspects are at the basis of a phase and are leading towards representing a logical order of the phases. Additionally, this research considers the newest technologies in an emerging and innovative market. Resultingly, a MM was derived where VCR and VCA concepts can be built on and which is up-to-date till 2022. The MM consisted of eight phases in the following order: No digitalization, Computerizing, Connecting, Exploring, Understanding, Predicting, Integrating, Simulating, and Automating. These phases were derived from 20 theoretical papers that were selected from SLR 1. An extensive list of potential MM phases was created, representing a detailed overview of big and smaller steps that an OEM could pass to reach the end of the Industry 4.0 transition. The initial MM consists of the MM phases that were most strongly supported by theory. It also ensured that the least amount of MM phases were selected that could form a MM that is understandable for OEMs. It makes that the smaller, more unimportant steps could be skipped to make it more comprehensive and understandable. It is clear to say that this MM includes the most critical and recent steps to complete the Industry 4.0 transition. The SLR has also dealt with the overlap in the phases from theory and combined smaller phases into larger ones when necessary.

The description and explanation of the individual MM phases differed for each. As expected, the most frequently identified phases in theory show the most extensive description of the phases. In this case, most information can be found for the phases Understanding, Predicting and Automating. In line with that finding, less information is available on the least mentioned phases, which is in this case, the Simulating phase, as research on that topic is still sparse. Nevertheless, a clear and comprehensive description of the phases is provided for each of the phases in the MM. These descriptions elaborate on changes the OEMs have to make in terms of technology, process, and people.

8.1.1.2. VCR

The VCR concepts were mainly found in the descriptions of the MM phases found above. These are complemented with the VCR concepts that were found in the papers in SLR 2, provided that it can be linked to a specific MM phase. As described above, the amount of information on the specific phases is highly dependent on the number of times a MM phases is pointed out in theory. As a result, there is an information overload regarding VCR for the phases Understanding, Predicting, and Automating. In addition, there is less information available about the remaining phases. As a result, some VCR concepts are identified by two or more papers in the data sample, and some of them were only identified ones. In contrast to compiling the MM, there is no threshold for the inclusion of VCR concepts. For that reason, all the ways to create value were listed in a table and filled in to compose the initial framework. The disadvantage of this method is that the VCR concepts are less theoretically grounded. However, the validity further improved whenever the framework was tested in the interviews. Noteworthy to say is that the number of times a VCR method is mentioned does not say anything about the power or originality of the factor, but it is just more widely addressed, and more theory is found about that topic. Whenever a MM phase is inadequately described, the number of novel insights regarding VCR also declines. It should be hold in mind that this does not mean that less value can be created in a particular phase.

In total, 55 ways of creating value are identified in the literature, divided over 6 MM phases in which VCR can be build on, and categorized into one of the two disciplines, maintenance or operations. Every part of the framework describes approximately five ways of creating value within that category. In some phases, numbers are mentioned. These are found in papers that did research on multiple companies in various industries. Noteworthy to say is that these numbers are not specified to a certain industry. Therefore, these numbers serve as a rough indication of the benefits that OEMs and end-users can expect.

8.1.1.3. VCA

This research sought for papers where value can be captured in each of the phases in the MM determined before. The key aspects of the MM phase from SLR 1 served as the basis for this search. As a result, VCA concepts can be linked directly to MM phases. Also, general VCA concepts that were found can also be linked indirectly to MM phases with specific business cases that were described.

24 papers were addressed and analyzed that could contribute to this study. Overall, 25 original ways for VCA was identified in the literature. However, not all of them could be linked to a specific MM phase in the model. Directly or indirectly, 15 of these concepts are associated with one or more MM phases in the model. Thus, the concepts that can be associated with a MM phase were integrated into the model. Again, there is no threshold for including the concepts in the framework due to the limited amount of information that could be found on this topic. Despite the three most frequent ways to capture value, pay-per-use, performance-based, and output-based, literature did mostly not agree on a VCA method that was specifically meant for a MM phase. The described VCA concepts were identified 9, 9, and 6 times, respectively. These are mentioned to be used from the Exploring phase, increasing revenues when passing the MM phases. Another concept that was frequently mentioned was a subscription (9), which can be used in the Understanding and Predicting phase. Also, SLAs (6) were frequently identified. SLAs are known as a traditional way of performing maintenance, already used in the No digitalization phase. Nevertheless, these can be upgraded in the subsequent phases by using Industry 4.0.

This SLR ensured that all the individually found VCA concepts were integrated into an overarching framework, making it more understandable for OEMs which VCA methods are applicable to their current state. To illustrate, pay-per-use business models can not be applied whenever the OEM is still in the Connecting phase. That is because there is yet no information available of the usage time of the machine. This framework points out that certain Industry 4.0 business models can only be applied in the phases they are in.
Now that this overview of VCA is present, it gives room for further research to add detailedness on each of the phases. One major finding is that SMEs are currently unable to earn back their Industry 4.0 investments. TCP is also yet unable to transform their business models drastically

8.1.2. Findings from interviews

8.1.2.1. Maturity Model

The interviews provided another viewpoint on the MM for TCP, in comparison to OEMs in general. The interviewees were asked to describe what they currently do in terms of Industry 4.0, how they prepare towards that phase, and what their vision is. This information gave novel insights into the form of the MM phases. The researchers could identify the MM phases based on the key aspects the interviewees mentioned. The phases No digitalization, Computerizing, Connecting, Exploring, Understanding, Predicting, Integrating, Simulating, and Automating were identified 2, 5, 8, 5, 7, 3, 0, 5, 1 times out of 8 times recognized by the interviewees, respectively. Nevertheless, in the validation phase did all the interviewees agree on the MM phases that were included in the model.

From this finding could be suggested that the Integrating phase is not as important to include in the model. Next to the fact that it is not recognized by the companies in the dataset, it is also the least frequently mentioned in the initial MM. Although the interviewees validated this phase, the Integrating phase is excluded from the final MM. The No digitalization phase and Automating phase are also not frequently mentioned. However, the No digitalization phase is not part of Industry 4.0, pointing out that these are easily forgotten to mention. To clarify, every TCP has been participating in the No digitalization phase before. In addition, the Automating is also not mentioned by the TCP. The industry 4.0 expert pointed out that this phase is yet too far for TCP. However, this will not say that this is unreachable in the future. This is proven by other Industry 4.0 technologies that seemed unreachable. For this reason, the No digitalization phase and Automating phase were held in the model.

Another point the interviewees made is that the Simulating phase can be used in multiple variants. Each of the variants mentioned could be exploited in another position in the MM. Contrastingly, the Industry 4.0 expert pointed out that these TCP are not aware of the functionalities of the Digital Twin, which is a key aspect in this phase. Therefore, the variants in the Simulating phase were neglected and held on the original position as found in theory and underlined by the Industry 4.0 expert.

Another point made by 4 of the OEMs in the data sample is that the Connecting phase and remote access could not be combined together. Here Connecting indicates that the IT/OT structure is sufficient to enable data exchange, while only VPN or Teamviewer is required for remote access. Thus, connecting serves as a crucial step towards data logging, while remote access could be done in parallel. Therefore, the choice is made to split these phases and make them parallel to each other.

The extension and validation of the MM gave various insights into the current state of the TCP. It is almost identical to the MM for OEMs in general, with a few minor adjustments. As described before, it is not convenient to determine the end-point of the Industry 4.0 transition for TCP since it is an innovative and emerging market. At this point, TCP seems to be participating mostly in the Understanding phase, with a vision toward the Predicting phase. This study is still unsure what the end-point is, questioning if TCPs can reach the Simulating and Automating phase in the future from a technological, organizational, and business viewpoint.

8.1.2.2. VCR

The interviewees were asked which benefits they experienced without pre-knowledge of the initial framework. Most of the novel VCR concepts that were mentioned by the interviewees had overlap with those that were identified in the literature. The novel concepts that were not identified earlier in the literature were considered to be included in the final framework. In this case, 5 novel insights were included in the final framework. The inclusion of these concepts depends on the number of times it is mentioned by the interviewee, in comparison to the number of companies that participate in these phases. As an example, the Connecting phase is elaborated on by all ten interviewees. Hence, cheaper support is mentioned four times, which is considered frequent. This is not comparable to the three interviewees that participate in the Predicting phase, where identification by two interviewees is considered frequent. The inclusion of the VCR concepts, therefore, depends on the frequency on the one hand and the interpretation of the researcher on the other hand. Nevertheless, the VCR concepts that were identified at least two times by interviewees were included anyhow. The novel ones that were identified only once, depending on the interpretation of the researcher. That means, if the factor is generalizable to multiple OEMs or adds a new creative view on the topic. The five novel insights that were included gave a more comprehensive view on the topic. Additionally, the existing VCR concepts were validated by showing the initial framework. All interviewees that participated in that MM phase have validated each of the concepts identified. This added extra validity to the VCR concepts identified in theory, which was unsure, as described earlier. That emphasizes the fact that the value created by OEMs also applies to TCP.

8.1.2.3. VCA

From the interviews appeared that the TCP currently uses mostly the same concepts as identified in the literature. Here, the interviewees identified 10 novel ways of capturing value in a certain phase that overlaps with earlier identified concepts found in theory. An additional 11 novel concepts were identified that were not earlier identified in theory in that particular phase. Handling the same strategy as with VCR, the inclusion of a factor depends on the frequency and generalizability in comparison to the number of companies that participate in this phase. At least, the concepts that were mentioned both in theory and practice were included in the final framework. The remaining concepts were interpreted by the researcher on the abovementioned aspects. As a result, 6 novel ways of capturing value were added to the final framework. The main findings were that the traditional SLA is still used in each of the phases, except for Exploring. This finding indicates that the TCP construct an even better SLA while improving its maintenance with Industry 4.0. From the Understanding phase, TCP developed preventive maintenance contracts, generating additional value. Also, TCP uses additional ways to create value, such as selling consumables based on data or providing additional services and upgrades. Extra revenue can be generated with the extra value they create for the end-user, based on data. The Industry 4.0 expert also states that everything comes together in the last phase, suggesting that XaaS (everything-as-a-service) is the optimal solution, where the business completely drives on services. The interviews also tempered the suggestion from the literature that VCA, such as pay-per-use, performance-based, and output-based are not currently used by TCP. These state that these business models are not yet financially attractive, even as organizational change is a considerable investment. However, some point out that this could be the future of manufacturing. Besides the novel insights provided, each of the interviewees validated the remaining findings addressed in theory. This enhanced the validity of the final framework significantly.

8.2. Managerial implications

Industry 4.0 is a highly innovative and evolving topic within manufacturing, receiving quite some research interest. However, most research focuses on the technological, strategic, and organizational aspects of Industry 4.0, while there is little interest in how to generate revenue with these technologies. Even though the benefits of Industry 4.0 are proven, TCP is not yet able to earn back the high investments that have to be made on forehand. Evenly, the TCP does not have the right knowledge, skills, and people to face these uncertainties. Prior research mainly describes how value can be created and captured in Industry 4.0 in general, such as pay-per-use business models. Industry 4.0 is considered to be a vague term of various technologies. This research accomplished that Industry 4.0 moved away from being a buzzword by clarifying which aspects comprise Industry 4.0.

This research applies to service managers, strategic managers, or CEOs of small and medium-sized OEMs (TCP) that have plans or have recently implemented some Industry 4.0 technologies. Service managers or strategic managers mostly determine the strategic roadmap in terms of vision for services, which is the application area of Industry 4.0. In even smaller companies, the CEO is responsible for these kind of decisions. This framework is beneficial for those who have plans to integrate one (or more) Industry 4.0 technologies, this framework can serve as a roadmap to determine the kind of technology and what this technology can accomplish in terms of benefits and revenues. For those who have already implemented some technologies, it may serve as an insights in where the company is in the roadmap and what has to happen to generate revenue. The MM that serves as the basis for the framework shows a clear roadmap of the newest developments as other TCP experience them, such as Digital Twin, which is underexposed in former MMs. Moreover, the MM gives a clear description of what steps are required to complete the phase in terms of technology, people, and process. It creates an understanding of which technology, skills, employees, and organizational changes are required to move from one phase to the next. TCP now know if the next phase is reachable with their current resources.

The framework is the first that shows a clear roadmap of possibilities in technologies, benefits and revenues all together. This may prevent tunnel vision by only knowing some parts of the Industry 4.0 revolution, such as remote access or predictive maintenance. This is especially applicable to TCP, that mostly do not have the knowledge or specialism in their company about this topic. It shows the current state of the company, but it can also be used to determine future developments. Moreover, TCP can use this study to translate the needs of the customer to a certain phase in the model and corresponding ways of capture value. To illustrate, end-users may indicate that they would like to see their OEE visible. In this case, the framework shows that the Exploring phase is sufficient to achieve this. The TCP can clearly see which steps are needed to go there and what the requirements are in terms of technology, process, and people. Additionally, it gives an indication how revenue can be generated.

This study is the first to view Industry 4.0 as several steps to be implemented and combine these in an overarching framework. Earlier research only described how business can be generated within one topic in Industry 4.0. This framework provides an overview of all the different phases and corresponding business opportunities. However, it may be hold in mind that the framework does not account to industry or country specific elements. As the framework is general and not specified to industry or country, it may not determine the impact of the benefits and revenue generated. As so, it only gives an indication of the different possibilities to create business in terms of VCR and VCA. This may specially apply for the quantifications in the framework. These numbers could not be copied one to one for each business, as these are industry specific. Therefore, the TCP should hold in mind that the numbers do not represent actual profits or benefits in their industry.

Besides the general and global approach of this research, TCP is able to learn from other best-practices by practical use-cases or examples. This research used TCP from multiple industries, which ensures that various perspectives are highlighted. Even though the results are mainly general, each TCP can give their own twist by searching similar business cases in the text. The majority of the framework is described by illustrative quotes. That is, providing detailed information about the specific method and how this method is executed within that particular business case. TCPs are able to identify these business cases and translate these into their own businesses

Moreover, this study is the first to combine VCR and VCA in one framework, which leverage persuasiveness in negotiations. That is, TCP can justify their cost structure to the end-user by showing them the benefits it deliver for them. Thus, account managers can use the benefits of a certain phase to reflect to the customer. With this information, the end-user may be more satisfied or convinced to implement the phase at a specified rate that is determined via the framework.

These managers of TCP as described before should hold in mind that the MM and value capture manners differ between larger OEMs and TCP. As expected, the outcome of the framework differs from general due to differences in knowledge, resources and cash flow. This framework reveals that the steps are smaller and different, even as the VCA methods. Most existing research that described VCA in larger OEMs describe that business models as pay-per-use and output-based are the standard, while this is not the case for TCP. It appeared that TCP does not apply such drastic changes, because of the negative cash flow implications. TCP mostly apply smaller methods, such as SLA and additional services. This finding should warn managers that VCA methods should not be copied one to one. Also, the importance of certain VCR methods shifts to other VCR methods that were more important to the current problems TCP faces. To illustrate, TCP experience more problems in personnel as larger OEMs, and therefore highlights the cut in workforce as an important benefit for some Industry 4.0 phases. Hence, this research adds to the limited amount of research about this topic of business generation for TCP.

8.3. Research contributions

Prior research discussed various ways to create and capture value for a specific type of technology within Industry 4.0. It shows VCA concepts either for one aspect of the Industry 4.0 revolution or either for the Industry 4.0 as a whole. This research shows a complete overview of best practices on how OEMs capture value for each smaller step in the Industry 4.0 revolution. For example, research explains how value can be captured for predictive maintenance. The main contribution to theory is that these methods are reviewed and combined into one overarching framework. This gives an overview of these methods together, making it possible for OEMs to determine what approach belongs to them. Another contribution to theory is the categorization of the VCR and VCA concepts for every smaller step in the Industry 4.0 transition, rather than an overall approach for the Industry 4.0 transition as a whole. To illustrate, research mainly indicates pay-per-use, performance-based, and output-based business models as a way to capture value with Industry 4.0 as a whole. But what kind of technology in this transition have to be implemented then. Also, it is the first research that combines VCR and VCA in a complete overview. Namely, these two concepts are both essential in a business model, strengthening each other in justification to the end-user. That is, it may serve as the groundwork to justify the charge of money

towards the end-user. The VCR concepts in the framework give a general overview on how SMEs can create value for the end-user within a particular phase in their transition, independent of the industry their working. This research provides examples and use-cases from best-practices by supporting the framework. This makes the framework more practical and understandable for the users of this framework.
The abovementioned findings addressed the research gap 1: *OEMs are lacking knowledge on how value can be created and captured for every phase in the Industry 4.0 revolution*.

These VCR and VCA concepts have to be based on individual steps in the Industry 4.0 revolution. Here, the systematic literature review ensured that an extensive base of literature of MMs was reviewed to combine the most important aspects of the MM for OEMs in general. Prior research mainly uses theoretical oriented papers, ignoring the practical relevance of this topic. This MM consists of a balanced set of papers from theory and practice. A significant part of the sample exists from consulting companies and other leading companies in the field. This makes that the MM ensured practical relevance and reflects the Industry 4.0 market from both a theoretical and practical perspective.
Prior research has constructed MMs with phases that are not able to find VCR and VCA concepts for. This study constructed a MM with technology or process as key aspects, which makes the researcher able to find phase-specific VCR and VCA concepts for. To conclude, there is yet no MM in the field that shows the exact phases as this MM. This MM represents the most up-to-date representation of the market from a technological viewpoint. It holds into account the newest technologies, such as Digital Twin, which was rarely mentioned in existing literature. The main function of the derived MM is to serve as a basis for the framework. Nevertheless, it fills some serious gaps in literature. It addresses gap 2, specified at the start of this research: *No research describes an Industry 4.0 roadmap that can serve as a basis for VCR and VCA concepts to build on.*

The relatively small amount of research focused on MMs for SMEs in the topic of Industry 4.0, even though there are large differences estimated on forehand. This research contributes to the existing literature in the field of MMs by constructing a MM that is specified to TCP (SMEs). The MM for TCP reveals major differences to the MM for OEMs. It shows that TCP follows other steps than OEMs does. More specifically, it is suggested that SMEs make smaller steps due to limited resources and knowledge. It also shows that SMEs are not yet participating in the later steps of the model, where the focus is still on monitoring of the machine. That makes that this research adds knowledge about the latest state of the TCPs in the Netherlands.
As suggested, the MM actually differed between OEMs in general and the TCP. TCP does not follow the same path and perform smaller steps in reaching the end-point. This addressed gap 2: *There is no evidence that an Industry 4.0 MM for OEMs in general follows the same steps as the MM for SMEs.*

As described earlier, limited research is available for SMEs on this topic. Due to the differences between the two in resources, there is no evidence that TCP and OEMs follow the same manner in creating business. This research shows best practices on how SMEs capture value for each smaller step in the Industry 4.0 revolution. Also, it reveals major differences on how value is created and captured between OEMs and TCP. To illustrate, prior research indicate that pay-per-use, performance-based, and output-based business models are the most ideal way to capture value as OEMs in general. However, in practice, it appeared that TCPs are not able to make such drastic changes due to cash flow. This research mentions less drastic methods such as integration in a SLA or smaller opportunities to generate revenues, which were earlier not identified in theory. These findings contribute to the findings that VCA methods are different for the two, and that TCP handle different methods to generate revenue. It shows that it is not plausible to blindly adopt VCA methods that are mentioned in theory for OEMs in general.
As described before, prior research focused on a certain value capture method within one area of research, not holding into account that OEMs do not have knowledge about the bigger picture. Especially for TCP, this is crucial. That makes the complete overview an essential contribution in the field of SMEs. Therefore, this research shows a complete overview of VCR and VCA on how TCP can thrive their businesses. The VCR concepts in the framework give a general overview on how SMEs can create value for the end-user within a particular phase in their transition, independent of the industry their working. However, there are less additions

of adjustments for the VCR methods. This finding indicates that VCR is relatively the same for both TCP and OEM.
This research also adds valuable best practices to theory on how SMEs capture value with use-cases from practices. Now that this overview of VCR and VCA is present, it gives room for further research to add detailedness on each of the phases.
Here, the last gap (4) is addressed, namely: *There is no evidence that the VCR and VCA concepts described in the literature also apply to SMEs*.

Conclusively, this research is the first work that gives a global overview of all business opportunities within the entire field of Industry 4.0 that apply to smart machining. It combines business opportunities that are described in individual phases of the Industry 4.0 revolution into one overarching framework. This overview ensures that TCP is able to identify business opportunities for every step in the Industry 4.0 revolution on the hand of VCR and VCA concepts. It has a significant contribution to the theory in the field of SMEs, which is sparse in terms of business generation. It also provides additional insights about the current status of TCP and problems they are facing towards Industry 4.0 maturity.

8.4. Limitations

Possible pitfalls are recognized at the beginning of this research. Most of them are addressed properly and coped with it throughout this research by taking several measures. Although these measures were taken to make the research unbiased as possible, research will never be clean from limitations. Therefore, this section elaborates on the possible limitations that arose during this study.

The main limitation is the global and general nature of the framework that is developed. The benefit of having a bigger picture of all the available methods in one overview makes that the detailedness is lacking. Although that all the concepts in the framework are described and most of them are supported by use-cases, this research did not dive deep into the concepts and how these should be used. Also, there is no mention of SME-specific lever mechanisms to use. For this, more specific research have to be explored. When not available, new possibilities for future research arise.

Another limitation arose with the working circumstances of the researcher. In most cases, a researcher already has pre-knowledge about a specific topic by working at the company wherefore the research is conducted. In this case, working at IXON could have created a bias toward the topic. It is inevitable that the researcher already has a biased view of the market by conversations with colleagues and customers from IXON.

The setup of both SLRs may have implications for the output. This research is considered to be very broad, showing up with a huge amount of literature to be investigated, where choices had to be made due to information overload. As a result, only the database Scopus, which primarily focuses on business research, is used as the main supplier for theory. This excluded information from other types of data, such as IEEE, which is originated in IS. The limitation is that one type of information source may lead to a tunnel vision view.

Another limitation is related to the construction of the MM. As the research is focused on finding VCR and VCA concepts, the key concepts in the individual phases are technologically oriented in the first place. That is, the order of the MM is primarily based on the technological sequence the Industry 4.0 transition suggests. Constructing a MM on technological aspects makes it more convenient to find corresponding ways to create and capture value, as if it is based on other capabilities. As a result, the researcher has dealt with other aspects as secondary outcomes. Thus, the order of the MM could look different if the main focus was not on technology, but other aspects.

As described earlier, the number of VCR concepts found is highly dependent on the description of the MM phases. It also depends on how often the MM phase is mentioned in SLR 1. This could indicate that less value can be created in the least mentioned phase in comparison to a more frequently mentioned phase.

Moreover, VCR is in some cases quantified in the literature and companies in the sample. As described before, OEMs can experience other numbers in the industry they participate in. It has to be held in mind that quantifications of the results can differ for industries and countries.

Most limitations are grounded in the practical part of this research, by selecting interviewees, conducting the interviews and analyzing the data. Starting with selecting the interviewees, it appeared that VCR and VCA is highly dependent on the industry and products that are made with the machine. For instance, it is much more easier to VCA Industry 4.0 whenever it is costly for a machine to break down, such the high mass industry. Contrastingly, Industry 4.0 is hard to VCA in robotics, doing low to medium production. Moreover, there is a lack of evidence if the concepts in this study differ per country. The literature sample consists of papers without a focus on a specific country, making it difficult to make conclusions about similarities of differences between countries. Also, the sample of participants is too small to develop a generalizable framework for all industries and within all MM phases. Following the latter, the entire framework could not be tested due to the immaturity of the TCP. The phases Computerizing, Connecting, Exploring, and Understanding gave sufficient input for extension and validation, while companies in the Predicting and Simulating phase were too immature to provide novel insights. The Integrating and Automating and Integrating phases could not be tested at all. Therefore, these phases were not extended properly and tested insufficiently. This limitation is partly refuted by the participation of the Industry 4.0 expert that has a broader knowledge of the market.
Moreover, it is questionable if the companies in the data sample could be labeled as best-practice. Some of them do not even capture value with Industry 4.0 over a more extended time period or make a profit with their technologies at all. Some companies have a strategy for capturing value, but there is no proven evidence in practice at all. These two abovementioned limitations validate the finding that the TCP market is still not ready yet, confirming the need for this research and further research on this topic.

The last limitations are applicable to the analysis of the data. The downside of explorative research is the interpretation bias of the researcher. This is primarily the case with the extension phase of the interview, as well as in the SLR. The most important bias is the naming and framing of the concepts and their meaning. For instance, the SLR and interviewees name several types and names of SLAs, each of them slightly different in purpose. It is the task of the researcher to recognize and address the types of SLAs and categorize them for further research. The same counts for the detailedness of the concepts. The researcher is limited in the description of the interviewee of a certain concept. It is not possible to go deep into certain concepts due to time restrictions. As a result, the concepts in the framework stay general, reducing the practical and managerial implications.

8.5. Future research

This section elaborates on the possibilities for further research that can already be extracted from the limitations described above. First, the main suggestion for further research arose from the given that this research's boundaries are broadly defined. This research has focused on the entire Industry 4.0 revolution, considering all possible VCR and VCA concepts that are known in the literature. This resulted in a general framework that gives a handhold to any TCP that would have a broad overview of the possibilities with Industry 4.0. Further research could focus on individual phases of the MM, going deeper into the VCR and VCA concepts of that particular phase. It could focus on VCA concepts and their structure in detail.

Secondly, given that the market is yet too immature for testing particular phases at the end of the MM, this could be seen as a task for future research. Novel insights could be constructed for the phases Predicting, Simulating, and Automating. It may also provide more validity to the theoretical insights for the abovementioned phases.

Thirdly, some OEMs in the dataset emphasized the difference of Industry 4.0 adoption between countries and between industries. There is yet insufficient evidence in this research that the findings differ for countries and industry. Therefore, further research could perform research for differences in countries and industries as mentioned by research and interviewees in this research.

Lastly, one could do more research on VCR within MM phases that were least mentioned in comparison to the more frequently mentioned phases. It could be that a particular MM phase is undervalued due to the distribution of information in SLR 1.

9. Conclusion

Industry 4.0 is a hot topic that receives quite some interest from research. TCPs remark that it is still a vague buzzword, but asks for high demand from the manufacturing market. It helps end-users to maximize production by minimizing breakdowns and optimizing the machine. TCP also sees the relative advantage of such solutions for the end-user, but does not know what can be the relative advantage for themselves. Yet, TCP do not have the know-how on how to know which technology could be valuable for them and how it can be charged back to the customer. At this moment, most TCP are not able to have a positive ROI with these technologies, resulting in a delayed adoption. This research helps to get a global overview of the variety of Industry 4.0 technologies in the market and their corresponding benefits and profits. An overarching framework could guide TCP in recognizing opportunities and making profit for each step they take, answering the main research question: "*How can TCP transform Industry 4.0 technologies into business opportunities for every phase in the roadmap?*"

To guide the researcher in developing this framework, the study is divided into several parts, which were reflected with five research questions. The first research question aimed at developing a MM from existing literature that represents the current Industry 4.0 market and is suitable to serve as a basis for VCR and VCA concepts. This part of the study is initially focused on the entire OEM market due to sparse information about TCP. RQ1 is formulated as follows: "*What does the current Industry 4.0 MM in manufacturing look like that can serve as a basis for VCR and VCA concepts?*". With the help of a SLR, eight MM phases were discovered that applied to the current manufacturing market. The starting phase of the MM is "No digitalization", where there is lacking knowledge of Industry 4.0 and no infrastructure to perform this on. Next, the "Computerizing" phase ensures that the groundwork for Industry 4.0 is performed by implementing digital solutions that are required for further steps. The third step is "Connecting", where the IT/OT from the previous step is connected for data practices in the next steps. These steps start with "Exploring", where OEE data can be monitored, followed by "Understanding", where important data can be visualized and contextualized to retrieve insights about the machine. Thereafter, the "Predicting" phase ensures that further improvements can be made by applying advanced data analysis techniques. The next step, "Integrating", ensures that the supply chain is connected to obtain horizontal integration. Thereafter, the machine can be visualized and simulated in the "Simulating" step. The last step is found to be "Automating", which accounts for a self-controlled factory. These eight phases provide a basis for the VCR and VCA concepts that were found with the second research question.

The second research question was formulated to explore how value can be created in each of the phases found above: "*How can OEMs create value for themselves and end-users in every phase of the Industry 4.0 MM?*". However, most of the papers found in RQ1 also describe how value can be created in each of the phases. As a result, RQ2 emerged from SLR 1, even providing a better fit towards the MM phases as initially intended. Thus, an individual SLR to answer RQ2 is not required anymore.

The third research question aimed to find ways to VCA value for each of the phases found in RQ1. RQ3 sounds: "*How can OEMs VCA value for every phase in the Industry 4.0 MM?*". Many ways of capturing value with Industry 4.0 were identified in the existing literature. Most of them could be directly linked to MM phases, and some of them were indirectly linked to MM phases via business cases.

Synthesisation of the results of RQ1, RQ2, and RQ3 has led to a framework where VCR and VCA concepts were explained for every phase in the MM. These results were separated into two disciplines where Industry 4.0 is most applied: Maintenance and operations. Starting with the "No digitalization" phase, OEMs can perform breakdown maintenance or periodical maintenance. In the Computerization phases were no VCR and VCA concepts found, indicating that it serves as a transition phase towards the next phases. "In the "Connecting" phase, OEMs can perform remote maintenance. The OEM can act as a transparency provider in the Exploring phase. Thereafter, OEMs can do preventive maintenance in the Understanding phase, while performing machine optimization to enhance their machine. One step further, OEMs can do predictive maintenance and predictive production in the Predicting phase. No VCA concepts are found in the Integrating phase, noting that this again serves as a transition phase toward the next steps. The Simulating phase can ensure that visual maintenance is done and scenario optimization for enhancement in operations. Lastly, in the Automating phase, the factory performs automated maintenance and operational excellence. Each of these aspects comes with its own ways to create value (VCR) and how to transform this value into profit, named VCA. These MM phases and each of its VCR and VCA concepts are apprehended in an overarching framework. However, this initial framework is not yet validated and specified to the TCP market.

The last research question accounts for the extension and validation of the initial framework in practice. RQ4 is formulated as follows: "*How can the initial framework be adjusted to enable a good fit for the TCP market?*" Here, eight interviews with mainly TCP and one Industry 4.0 expert have reflected on the initial framework, on the one hand, providing novel additions to the framework and, on the other hand, validating the insights found in the literature. This resulted in several additions to the existing framework and two main adjustments. Firstly, remote maintenance can be performed in parallel with the data logging phases. Secondly, Integrating is found to be unimportant and not adding value, resulting in exclusion from the framework. Another main finding is that TCP best practices still mainly integrate their Industry 4.0 solutions into an improved SLA, and drastic business model transformations are not yet applied.

Conclusively, this research provided a handhold to TCP by employing Industry 4.0 technologies and integrating these in their businesses to generate revenue. The final framework shows a general overview of how best practices on TCP have created and captured value for every phase of the MM. It shows the complete work on Industry 4.0 VCR and VCA concepts from a broader perspective by synthesizing existing literature on this topic.

10. References

Agarwal, G. K., Simonsson, J., Magnusson, M., Hald, K. S., & Johanson, A. (2022). Value-capture in digital servitization. *Journal of Manufacturing Technology Management*, *33*(5), 986–1004. https://doi.org/10.1108/JMTM-05-2021-0168

Agostini, L., & Nosella, A. (2020). The adoption of Industry 4.0 technologies in SMEs: results of an international study. *Management Decision*, *58*(4), 625–643. https://doi.org/10.1108/MD-09-2018-0973

Alam, M. K. (2021). A systematic qualitative case study: questions, data collection, NVivo analysis and saturation. *Qualitative Research in Organizations and Management: An International Journal*, *16*(1), 1–31. https://doi.org/10.1108/QROM-09-2019-1825

Alencar, A. B., De Oliveira, M. C. F., & Paulovich, F. V. (2012). Seeing beyond reading: A survey on visual text analytics. In *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery* (Vol. 2, Issue 6, pp. 476–492). Wiley-Blackwell. https://doi.org/10.1002/widm.1071

Almeida, F., Duarte Santos, J., & Augusto Monteiro, J. (2020). The Challenges and Opportunities in the Digitalization of Companies in a Post-COVID-19 World. *IEEE Engineering Management Review*, *48*(3), 97–103. https://doi.org/10.1109/EMR.2020.3013206

Arnold, C. (2017). *Innovative Business Models for the Industrial Internet of Things Integration of Industry 4.0 within the entire value chain View project Sustainable Smart Industry-Industry 4.0 as a Future Model of Sustainable Industrial Value Creation View project*. https://www.researchgate.net/publication/316684694

Asdecker, B., & Felch, V. (2018). Development of an Industry 4.0 maturity model for the delivery process in supply chains. *Journal of Modelling in Management*, *13*(4), 840–883. https://doi.org/10.1108/JM2-03-2018-0042

Backlund, F., Chronéer, D., & Sundqvist, E. (2014). Project Management Maturity Models – A Critical Review. *Procedia - Social and Behavioral Sciences*, *119*, 837–846. https://doi.org/10.1016/j.sbspro.2014.03.094

Baier, K.: 1966, 'What is Value? An Analysis of the Concept', in K. Baier and N. Rescher (eds.), Values and the Future: The Impact of Technological Change on American Values (The Free Press, New York), pp. 33–67.

Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing maturity models for IT management. Business & Information Systems Engineering, 1(3), 213-222.

Benešová, A., Basl, J., Tupa, J., & Steiner, F. (2021). Design of a business readiness model to realise a green industry 4.0 company. *International Journal of Computer Integrated Manufacturing*, *34*(9), 920–932. https://doi.org/10.1080/0951192X.2021.1946858

Björkdahl, J. (2020). Strategies for Digitalization in Manufacturing Firms. *California Management Review*, *62*(4), 17–36. https://doi.org/10.1177/0008125620920349

Bosman, L., Hartman, N., & Sutherland, J. (2020). How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management*, *31*(5), 1117–1141. https://doi.org/10.1108/JMTM-09-2018-0283

Burggraf, P., Dannapfel, M., Bertling, M., & Xu, T. (2018, October 4). Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises. *PICMET 2018 - Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The Engine for Economic Growth, Proceedings*. https://doi.org/10.23919/PICMET.2018.8481980

Burström, T., Parida, V., Lahti, T., & Wincent, J. (2021). AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research. *Journal of Business Research*, *127*, 85–95. https://doi.org/10.1016/j.jbusres.2021.01.016

Caiado, R. G. G., Scavarda, L. F., Gavião, L. O., Ivson, P., Nascimento, D. L. D. M., & Garza-Reyes, J. A. (2021). A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management. *International Journal of Production Economics*, *231*. https://doi.org/10.1016/j.ijpe.2020.107883

Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, *107*, 22–32. https://doi.org/10.1016/j.compind.2019.01.007

Charro, A., & Schaefer, D. (2018). *Cloud Manufacturing as a New Type of Product-Service-System*. https://doi.org/10.1080/0951192X.2018.1493228?journalCode=tcim20

Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to industry 4.0 adoption and its performance implications: An empirical investigation of emerging economy. *Journal of Cleaner Production*, *285*. https://doi.org/10.1016/j.jclepro.2020.124809

Chen, Y., Visnjic, I., Parida, V., & Zhang, Z. (2021). On the road to digital servitization – The (dis)continuous interplay between business model and digital technology. *International Journal of Operations and Production Management*, *41*(5), 694–722. https://doi.org/10.1108/IJOPM-08-2020-0544

Chesbrough, H., Lettl, C., & Ritter, T. (2018). Value Creation and Value Capture in Open Innovation. *Journal of Product Innovation Management*, *35*(6), 930–938. https://doi.org/10.1111/jpim.12471

Colli, M., Madsen, O., Berger, U., Møller, C., Wæhrens, B. V., & Bockholt, M. (2018). *Contextualizing the outcome of a maturity assessment for Industry 4.0*. *51*(11), 1347–1352. https://doi.org/10.1016/j.ifacol.2018.08.343

Creswell, J. W. (2014). A concise introduction to mixed methods research. SAGE publications.

Creswell, J. W., & Poth, CN. (2007). *Qualitative inquiry & research design : choosing among five approaches*. Sage Publications.

Dalmarco, G., Ramalho, F. R., Barros, A. C., & Soares, A. L. (2019). Providing industry 4.0 technologies: The case of a production technology cluster. *Journal of High Technology Management Research*, *30*(2). https://doi.org/10.1016/j.hitech.2019.100355

Damant, L., Forsyth, A., Farcas, R., Voigtländer, M., Singh, S., Fan, I. S., & Shehab, E. (2021). Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins. *Advances in Transdisciplinary Engineering*, *16*, 171–180. https://doi.org/10.3233/ATDE210095

De Bruin, T., Rosemann, M., Freeze, R., & Kaulkarni, U. (2005). Understanding the main phases of developing a maturity assessment model. In Australasian Conference on Information Systems (ACIS) (pp. 8-19). Australasian Chapter of the Association for Information Systems.

Deloitte. (2017). *Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure*.

Deloitte. (2020). *Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing*.

Eckelt, D., Dülme, C., Gausemeier, J., & Hemel, S. (2016). Detecting White Spots in Innovation-Driven Intellectual Property Management. In *Technology Innovation Management Review* (Vol. 6, Issue 7). www.timreview.ca

Ehret, M., & Wirtz, J. (2017). Unlocking value from machines: business models and the industrial internet of things. In *Journal of Marketing Management* (Vol. 33, Issues 1–2, pp. 111–130). Routledge. https://doi.org/10.1080/0267257X.2016.1248041

European Commission. (2003). SME definition. Internal Market, Industry, Entrepreneurship and SMEs. https://ec.europa.eu/growth/smes/sme-definition_nl

Frank, A. G., Mendes, G. H. S., Ayala, N. F., & Ghezzi, A. (2019). Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change*, *141*, 341–351. https://doi.org/10.1016/j.techfore.2019.01.014

Fraunhofer & VDMA. (2021). *Guideline Retrofit for Industrie 4.0*.

G. Schuh, J. Frank, P. Jussen, C. Rix, T. Harland, & IEEE International Technology Management Conference (2018 : Stuttgart, G. (2018). *Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry*. 8 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).

Gaiardelli, P., Pezzotta, G., Rondini, A., Romero, D., Jarrahi, F., Bertoni, M., Wiesner, S., Wuest, T., Larsson, T., Zaki, M., Jussen, P., Boucher, X., Bigdeli, A. Z., & Cavalieri, S. (2021). Product-service systems evolution in the era of Industry 4.0. *Service Business*, *15*(1), 177–207. https://doi.org/10.1007/s11628-021-00438-9

Galletta, A.M. (2013). Mastering the Semi Structured Interview and Beyond. NYU Press, New York. https://doi.org/10.18574/nyu/9780814732939.001.0001

Garousi, V., Felderer, M., & Mäntylä, M. V. (2019). Guidelines for including grey literature and conducting multivocal literature reviews in software engineering. *Information and Software Technology*, *106*, 101–121. https://doi.org/10.1016/j.infsof.2018.09.006

Gebauer, H., Arzt, A., Kohtamäki, M., Lamprecht, C., Parida, V., Witell, L., & Wortmann, F. (2020). How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies. *Industrial Marketing Management*, *91*, 429–441. https://doi.org/10.1016/j.indmarman.2020.10.006

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, *29*(6), 910–936. https://doi.org/10.1108/JMTM-02-2018-0057

Gill, M., & Vanboskirk, S. (2016). *The Digital Maturity Model 4.0 Benchmarks: Digital Business Transformation Playbook*.

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2013). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods*, *16*(1), 15–31. https://doi.org/10.1177/1094428112452151

Glaser, B. G. (1992). Basics of grounded theory analysis: Emergence vs. forcing. Mill Valley, CA: Sociology Press.

Gökalp, E., Şener, U., & Eren, P. E. (2017). Development of an assessment model for industry 4.0: Industry 4.0-MM. In *Communications in Computer and Information Science* (Vol. 770). https://doi.org/10.1007/978-3-319-67383-7_10

Guest, G., Bunce, A., & Johnson, L. (2006). How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. *Field Methods*, *18*(1), 59–82. https://doi.org/10.1177/1525822X05279903

Gupta, B. K., & Rastogi, V. (2022). Integration of technology to access the manufacturing plant via remote access system - A part of Industry 4.0. *Materials Today: Proceedings*, 3497–3505. https://doi.org/10.1016/j.matpr.2021.11.135

Häckel, B., Karnebogen, P., & Ritter, C. (2022). AI-based industrial full-service offerings: A model for payment structure selection considering predictive power. *Decision Support Systems*, *152*. https://doi.org/10.1016/j.dss.2021.113653

Hair, Jr., J. F., Money, A. H., Samouel, P. & Page, M. (2007). Research methods for business. Chichester: John Willey & Sons Ltd.

Han, Y., & Song, Y. H. (2003). Condition monitoring techniques for electrical equipment - A literature survey. In *IEEE Transactions on Power Delivery* (Vol. 18, Issue 1, pp. 4–13). https://doi.org/10.1109/TPWRD.2002.801425

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, *15*(9), 1277–1288. https://doi.org/10.1177/1049732305276687

Internet of Things Global Standards Initiative. (n.d.). ITU. Retrieved March 20, 2022, from https://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx

Indrawan, H., Cahyo, N., Simaremare, A., Aisyah, S., Paryanto P., & Munyensanga, P. (2019). *A Developed Analysis Models for Industry 4.0 toward Smart Power Plant System Process*. 2nd International Conference on Information and Communications Technology.

Jæger, B., & Halse, L. L. (2017). The IoT technological maturity assessment scorecard: A case study of norwegian manufacturing companies. In *IFIP Advances in Information and Communication Technology* (Vol. 513). https://doi.org/10.1007/978-3-319-66923-6_17

Javaid, M., Abid Haleem, Pratap Singh, R., Rab, S., & Suman, R. (2021). Upgrading the manufacturing sector via applications of Industrial Internet of Things (IIoT). *Sensors International*, *2*. https://doi.org/10.1016/j.sintl.2021.100129

Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. In *Journal of Advanced Nursing* (Vol. 72, Issue 12, pp. 2954–2965). Blackwell Publishing Ltd. https://doi.org/10.1111/jan.13031

Kampker, A., Jussen, P., & Moser, B. (2022). *Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture*. Proceedings of the 2018 IEEE IEEM1084Authorized licensed use limited to: Eindhoven University of Technology. Downloaded on October 03,2022 at 14:17:02 UTC from IEEE Xplore. Restrictions apply. .

Kapur, P. K. (n.d.). *Springer Proceedings in Business and Economics Quality, IT and Business Operations Modeling and Optimization*. http://www.springer.com/series/11960

Karre, H., Hammer, M., Kleindienst, M., & Ramsauer, C. (2017). Transition towards an Industry 4.0 State of the LeanLab at Graz University of Technology. *Procedia Manufacturing*, *9*, 206–213. https://doi.org/10.1016/j.promfg.2017.04.006

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., & Baines, T. (2019). Digital servitization business models in ecosystems: A theory of the firm. *Journal of Business Research*, *104*, 380–392. https://doi.org/10.1016/j.jbusres.2019.06.027

Kohtamäki, M., Rabetino, R., Parida, V., Sjödin, D., & Henneberg, S. (2022). Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems. In *Industrial Marketing Management* (Vol. 105, pp. 253–267). Elsevier Inc. https://doi.org/10.1016/j.indmarman.2022.06.010

Kvale, S. (2012). Doing interviews. Sage.

Langley, D. J. (2022). Digital Product-Service Systems: The Role of Data in the Transition to Servitization Business Models. *Sustainability (Switzerland)*, *14*(3). https://doi.org/10.3390/su14031303

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business and Information Systems Engineering*, *6*(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Lee, J., Jun, S., Chang, T. W., & Park, J. (2017). A smartness assessment framework for smart factories using analytic network process. *Sustainability (Switzerland)*, *9*(5). https://doi.org/10.3390/su9050794

Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). *VALUE CREATION AND VALUE CAPTURE: A MULTILEVEL PERSPECTIVE*.

Leyh, C., Bley, K., Schaffer, T., & Forstenhausler, S. (2016). SIMMI 4.0-a maturity model for classifying the enterprise-wide it and software landscape focusing on Industry 4.0. *Proceedings of the 2016 Federated Conference on Computer Science and Information Systems, FedCSIS 2016*, 1297–1302. https://doi.org/10.15439/2016F478

Li, C., & Tomlin, B. (2022). After-Sales Service Contracting: Condition Monitoring and Data Ownership. *Manufacturing and Service Operations Management*, *24*(3), 1494–1510. https://doi.org/10.1287/msom.2022.1095

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. In *International Journal of Production Research* (Vol. 55, Issue 12, pp. 3609–3629). Taylor and Francis Ltd. https://doi.org/10.1080/00207543.2017.1308576

Lin, T.-C., Wang, K. J., & Sheng, M. L. (2020). To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises. *International Journal of Computer Integrated Manufacturing*, *33*(1), 102–115. https://doi.org/10.1080/0951192X.2019.1699255

Lincoln Y, Guba E (1985) Naturalistic Inquiry. London: Sage.

Linde, L., Frishammar, J., & Parida, V. (2021). Revenue Models for Digital Servitization: A Value Capture Framework for Designing, Developing, and Scaling Digital Services. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2021.3053386

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. In *Journal of Industrial Information Integration* (Vol. 6, pp. 1–10). Elsevier B.V. https://doi.org/10.1016/j.jii.2017.04.005

Maanen, J. Van. (1979). Reclaiming Qualitative Methods for Organizational Research: A Preface. In *Quarterly* (Vol. 24, Issue 4).

Madsen, D. Ø. (2019). The emergence and rise of industry 4.0 viewed through the lens of management fashion theory. *Administrative Sciences*, *9*(3). https://doi.org/10.3390/admsci9030071

Maghazei, O., & Zürich, E. (2017). *Implementation of Industry 4.0 technologies: what can we learn from the past?* http://www.emeraldinsight.com/loi/wcdm].

Marinas, M., Dinu, M., Socol, A. G., & Socol, C. (2021). The technological transition of european manufacturing companies to industry 4.0. is the human resource ready for advanced digital technologies? the case of romania. *Economic Computation and Economic Cybernetics Studies and Research*, *55*(2), 23–41. https://doi.org/10.24818/18423264/55.2.21.02

Matthyssens, P. (2019). Reconceptualizing value innovation for Industry 4.0 and the Industrial Internet of Things. In *Journal of Business and Industrial Marketing* (Vol. 34, Issue 6, pp. 1203–1209). Emerald Group Holdings Ltd. https://doi.org/10.1108/JBIM-11-2018-0348

Mettler, T. (2009). A design science research perspective on maturity models in information systems.

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). In *Journal of Manufacturing Systems* (Vol. 49, pp. 194–214). Elsevier B.V. https://doi.org/10.1016/j.jmsy.2018.10.005

Morse, J. (1995). The significance of saturation. *SAGE*.

Mostafa, F., Tao, L., & Yu, W. (2021). An effective architecture of digital twin system to support human decision making and AI-driven autonomy. *Concurrency and Computation: Practice and Experience*, *33*(19). https://doi.org/10.1002/cpe.6111

Müller, J. M. (2019). Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users. *Journal of Manufacturing Technology Management*, *30*(8), 1127–1142. https://doi.org/10.1108/JMTM-01-2018-0008

Okoli, C., & Schabram, K. (2010). *Working Papers on Information Systems A Guide to Conducting a Systematic Literature Review of Information Systems Research A Guide to Conducting a Systematic Literature Review of Information Systems Research*.

Paiola, M., & Gebauer, H. (2020). Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms. *Industrial Marketing Management*, *89*, 245–264. https://doi.org/10.1016/j.indmarman.2020.03.009

Paschou, T., Rapaccini, M., Adrodegari, F., & Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management*, *89*, 278–292. https://doi.org/10.1016/j.indmarman.2020.02.012

Passlick, J., Dreyer, S., Olivotti, D., Grützner, L., Eilers, D., & Breitner, M. H. (2020a). *Predictive maintenance as an internet of things enabled business model: A taxonomy*. https://doi.org/10.1007/s12525-020-00440-5/Published

Passlick, J., Dreyer, S., Olivotti, D., Grützner, L., Eilers, D., & Breitner, M. H. (2020b). *Predictive maintenance as an internet of things enabled business model: A taxonomy*. https://doi.org/10.1007/s12525-020-00440-5/Published

Patton, M. Q. (1990). Qualitative evaluation and research methods. SAGE Publications, inc.

Placzek, M., Eberling, C. and Gausemeier, J. (2015) 'Conception of a knowledge management system for technologies', Proceedings of 24th International Association for Management of Technology Conference, 8–11 June, 2015 International Association for Management of Technology (IAMOT), Cape Town, Vol. 24, pp.1646–1663.

Priem, R. L. (2007). A Consumer Perspective on Value Creation. In *Source: The Academy of Management Review* (Vol. 32, Issue 1). https://about.jstor.org/terms

Proença, D., & Borbinha, J. (2016). Maturity models for information systems-a state of the art. Procedia Computer Science, 100, 1042-1049.

PWC. (2016). *Industry 4.0: Building the digital enterprise*. www.pwc.com/industry40

PwC. (2018). *Predictive Maintenance - Beyond the hype*.

Rafael, L. D., Jaione, G. E., Cristina, L., & Ibon, S. L. (2020). An Industry 4.0 maturity model for machine tool companies. *Technological Forecasting and Social Change*, *159*. https://doi.org/10.1016/j.techfore.2020.120203

Rockwell. (2014). *The Connected Enterprise Maturity Model*.

Rockwell. (2021). *Smart Machines Maturity model*.

Rowley, J. (2012). Conducting research interviews. *Management Research Review*, *35*(3–4), 260–271. https://doi.org/10.1108/01409171211210154

Santos, R. C., & Martinho, J. L. (2020). An Industry 4.0 maturity model proposal. *Journal of Manufacturing Technology Management*, *31*(5), 1023–1043. https://doi.org/10.1108/JMTM-09-2018-0284

Saravanan, G., Parkhe, S. S., Thakar, C. M., Kulkarni, V. V., Mishra, H. G., & Gulothungan, G. (2022). Implementation of IoT in production and manufacturing: An Industry 4.0 approach. *Materials Today: Proceedings*, *51*, 2427–2430. https://doi.org/10.1016/j.matpr.2021.11.604

Sayem, A., Biswas, P. K., Khan, M. M. A., Romoli, L., & Dalle Mura, M. (2022). Critical Barriers to Industry 4.0 Adoption in Manufacturing Organizations and Their Mitigation Strategies. *Journal of Manufacturing and Materials Processing*, *6*(6). https://doi.org/10.3390/jmmp6060136

Schaefer, D., Walker, J., & Flynn, J. (2017). A data-driven business model framework for value capture in Industry 4.0. *Advances in Transdisciplinary Engineering*, *6*, 245–250. https://doi.org/10.3233/978-1-61499-792-4-245

Schuh, G., Anderl, R., Dumitrescu, R., & Krüger, A. (2020). *acatech STUDY Industrie 4.0 Maturity Index*.

Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, *52*, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Sekaran, U. & Bougie, R. (2010). Research methods for business: A skill building approach (5th ed.). Chichester: John Willey & Sons Ltd

Simpson, J., & Weiner, E. (1989). The Oxford English Dictionary. 20 Volume Set.

Sjödin, D., Parida, V., Jovanovic, M., & Visnjic, I. (2020). Value Creation and Value Capture Alignment in Business Model Innovation: A Process View on Outcome-Based Business Models. *Journal of Product Innovation Management*, *37*(2), 158–183. https://doi.org/10.1111/jpim.12516

Sjödin, D. R., Parida, V., Leksell, M., & Petrovic, A. (2018). Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing. *Research Technology Management*, *61*(5), 22–31. https://doi.org/10.1080/08956308.2018.1471277

Sjödin, Parida, & Visnjic. (2022). How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems. *California Management Review*, *64*(3), 49–77. https://doi.org/10.1177/00081256211059140

Sony, M., Antony, J., Mc Dermott, O., & Garza-Reyes, J. A. (2021). An empirical examination of benefits, challenges, and critical success factors of industry 4.0 in manufacturing and service sector. *Technology in Society*, *67*. https://doi.org/10.1016/j.techsoc.2021.101754

Suppatvech, C., Godsell, J., & Day, S. (2019). The roles of internet of things technology in enabling servitized business models: A systematic literature review. Industrial Marketing Management, 82, 70-86.

Ustundag, A., & Cevikcan, E. (2018). *Industry 4.0: Managing The Digital Transformation*. Springer International Publishing. https://doi.org/10.1007/978-3-319-57870-5

Vandermerwe, S., & Rada, J. (1988). Servitization of Business: Adding Value by Adding Services. In *Europtvn Mannyement lournal* (Vol. 6, Issue 0).

Verhoef, P. C., & Bijmolt, T. H. A. (2019). Marketing perspectives on digital business models: A framework and overview of the special issue. In *International Journal of Research in Marketing* (Vol. 36, Issue 3, pp. 341–349). Elsevier B.V. https://doi.org/10.1016/j.ijresmar.2019.08.001

Vijaya Kumar, N., Karadgi, S., & Kotturshettar, B. B. (2020). Review of research issues and challenges of maturity models concerning industry 4.0. *IOP Conference Series: Materials Science and Engineering*, *872*(1). https://doi.org/10.1088/1757-899X/872/1/012006

Wang, N., Ren, S., Liu, Y., Yang, M., Wang, J., & Huisingh, D. (2020). An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode. *Journal of Cleaner Production*, *277*. https://doi.org/10.1016/j.jclepro.2020.123365

Weber, C., Königsberger, J., Kassner, L., & Mitschang, B. (2017). M2DDM - A Maturity Model for Data-Driven Manufacturing. *Procedia CIRP*, *63*, 173–178. https://doi.org/10.1016/j.procir.2017.03.309

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. In *Quarterly* (Vol. 26, Issue 2).

Wendler, R. (2012). The maturity of maturity model research: A systematic mapping study. *Information and Software Technology*, *54*(12), 1317–1339. https://doi.org/10.1016/j.infsof.2012.07.007

Wolfswinkel, J. F., Furtmueller, E., & Wilderom, C. P. M. (2013). Using grounded theory as a method for rigorously reviewing literature. In *European Journal of Information Systems* (Vol. 22, Issue 1, pp. 45–55). Palgrave Macmillan Ltd. https://doi.org/10.1057/ejis.2011.51

Wortmann, F., & Flüchter, K. (2015). Internet of Things: Technology and Value Added. In *Business and Information Systems Engineering* (Vol. 57, Issue 3, pp. 221–224). Gabler Verlag. https://doi.org/10.1007/s12599-015-0383-3

Xia, Q., Jiang, C., Yang, C., Zheng, X., Pan, X., Shuai, Y., & Yuan, S. (2019). A method towards smart manufacturing capabilities and performance measurement. *Procedia Manufacturing*, *39*, 851–858. https://doi.org/10.1016/j.promfg.2020.01.415

Xu, L. Da, Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, *56*(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Zawra, L. M., Mansour, H. A., Eldin, A. T., & Messiha, N. W. (2017, August). Utilizing the internet of things (IoT) technologies in the implementation of industry 4.0. In Proceedings of the International Conference on Advanced Intelligent Systems and Informatics 2017 (pp. 798-808). Cham: Springer International Publishing.

Zhou, K., Liu, T., & Zhou, L. (2016). Industry 4.0: Towards future industrial opportunities and challenges. *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015*, 2147–2152. https://doi.org/10.1109/FSKD.2015.7382284

11. Appendices

11.1. Appendix 1: Grey literature

Grey literature can be defined as "literature that is produced on all levels of government, academics, business and industry in print and electronic formats, but which is not controlled by commercial publishers, i.e., where publishing is not the primary activity of the producing body" (Garousi et al., 2019). The grey literature in this study was mainly derived from consulting companies or governmental institutions. Grey literature is an essential source of information due to the richness of practical research contributions of consulting and automation companies. As these are not always accessible via databases, an internet search is required (Garousi et al., 2019). Internet searches enabled finding information from important industry 4.0 consultants in the market. Also, grey literature is frequently cited in theoretical papers and noted in the corresponding tables within the SLR. The grey literature used in each SLR can be seen in the tables below.

11.1.1. SLR 1

Table 15: Sample of grey literature used in SLR 1

Title	Author(s)/Institute	Publication date	Description	Source
IMPULS - Industrie 4.0 Readiness model	VDMA - Verband Deutscher Machinen- und Anlagenbau	2015	Institute that represents more than 3400 German companies in the manufacturing industry, focusing on SMEs	Internet Also cited by Altan Koyuncu et al. (2021) - Zoubek & Simon (2021) - Castelo-Branco et al. (2022) - Dikhanbayeva (2020) - Çınar et al. (2021) - Collie et al. (2019) - Nick et al. (2020) in the first selection sample of SLR 1
The Connected Enterprise Maturity Model	Rockwell Automation	2014	American market leader on industrial automation and Industry 4.0 transformation	Internet Also cited by Altan Koyuncu et al. (2021) - Castelo-Branco et al. (2022) - Çınar et al. (2021) - Collie et al. (2019) in the first selection sample of SLR 1
Industry 4.0 Maturity Index	(Schuh et al., 2020) Acatech - German	2020	Acatech is an independent research institute that represents the interests of German	Internet

	Academy of Science and Engineering & RWTH Aachen University		technical science research	Also cited by Altan Koyuncu et al. (2021) - Zoubek & Simon (2021) - Castelo-Branco et al. (2022) - Çınar et al. (2021) - Busch et al. (2019) - Collie et al. (2019) - Melnik et al. (2020) - Suparno & Ardi (2020) - Nick et al. (2020) in the first selection sample of SLR 1
Industry 4.0: Building the digital enterprise	Pwc - PricewaterhouseCoopers	2016	PwC is the world's second largest consulting company providing value-added services to companies	Internet Also cited by Altan Koyuncu et al. (2021) - Castelo-Branco et al. (2022) - Dikhanbayeva (2020) - Zoubek & Simon (2021) - Çınar et al. (2021) - Collie et al. (2019) in the first selection sample of SLR 1
Esko Digital Maturity Model	Esko	-	Esko is a Belgium provider of integrated software and hardware solutions for the packaging industry	
Industrie 4.0 quo vadis?	Fraunhofer ISI - Systems and Innovation Research	2015	German institute that focus on applied science research. ISI is a research unit that is specialized on System and Innovation Research	Internet Also cited by Elibal & Özceylan (2021) in the first selection sample of SLR 1
Smart Machine Maturity Model	Rockwell automation	2021	American market leader on industrial automation and Industry 4.0 transformation	Internet Also cited by Rafael et al. (2020) in the first selection sample of SLR 1
Guideline Retrofit for Industrie 4.0	VDMA - Anderl, R., Picard, A., Wang, Y., Fleischer, J., Dosch, S., Klee, B., & Bauer, J.	2021	Institute that represents more than 3400 German companies in the manufacturing industry, focusing on SMEs	Internet Also cited by Mittal et al. (2018) in the first selection sample of SLR 1

11.1.2. SLR 2

Table 16: Sample of grey literature used in SLR 2

Title	Author	Publication date	Description	Source
Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	2020	Industry association for the information and telecommunication industry. One of BITKOM's core tasks is the digital transformation for OEMs.	Internet

Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	2020	One of the leading consulting companies in the Netherlands, focusing on the financial and business aspects.	Internet
Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	2017	One of the leading consulting companies in the Netherlands, focusing on the financial and business aspects.	Internet
Predictive maintenance: Beyond the hype	PwC	2018	PwC is the world's second largest consulting company providing value-added services to companies	(Damant et al., 2021)
Time to listen to your machines.	IBM	2016	IBM is one of the biggest IT company worldwide. One of their core activities are Cloud services and IT consulting	(Damant et al., 2021)

11.2. Appendix 2: Assessment criteria

11.2.1. SLR 1

Table 17: Assessment criteria for SLR 1

Criteria	Score	Description
First check (FC)	Yes	The paper passed the first check, allowing to be assessed on other criteria
	No	The paper did not suit research, no further assessment required
Applicability (A)	1	Industry 4.0 technologies have nothing to do with manufacturing (organisational processes e.g.)
	2	Uses Industry 4.0 technologies for other manufacturing processes (logistics e.g.)
	3	Industry 4.0 focus is used on an organizational level throughout the whole company
	4	Industry 4.0 used mainly for smart manufacturing
	5	MM only focuses on Industry 4.0 for smart machining
Target (T)	1	Other sectors as manufacturing

	2	Manufacturing
	3	Manufacturing and SMEs
Detail (D)	1	No description, no clue what the MM is about
	2	Sparse description of the phases
	3	General idea of what the phases are about
	4	Extensive description
	5	Comprehensive description by multiple aspects as technology, process, and people
Orientation (O)	1	No technology or process mentioned in the MM
	2	At least one technology is mentioned in the MM
	3	Sometimes a technology forms the basis for a phase in the MM
	4	Most of the time, technology forms the basis for a phase in the MM
	5	A technology forms the basis for every phase in the MM

11.2.2. SLR 2

Table 18: Assessment criteria of SLR 2

Criteria	Score	Description
First check (FC)	Yes	The paper passed the first check, allowing to be assessed on other criteria
	No	The paper did not suit research, no further assessment required
Subject (S)	1	VCA is not mentioned
	2	VCA is mentioned but is not part of the papers' main subject
	3	VCA is part of a more prominent subject (business models, e.g.)
	4	VCA comprises the main subject of the paper
	5	Explicit focus on VCA, and no other concepts are mentioned
OEM-focused (O)	1	Has no focus on the OEM's point of view
	2	Focus from the viewpoint of the end-user, no or less viewpoint of the OEM
	3	Describe VCA for both the viewpoint of the OEM and end-user
	4	Describes VCA mainly from the OEM's viewpoint
	5	Has a clear focus from the OEM's viewpoint
Target (T)	1	Other sectors as manufacturing
	2	Manufacturing
	3	Manufacturing and SMEs
Focus (F)	1	Describes VCA for Industry 4.0 in general
	2	Describe VCA for certain aspects in Industry 4.0
	3	Described VCA for a specific aspect in Industry 4.0

11.3. Appendix 3: First selection round

11.3.1. SLR 1

The table shows for every paper in the first selection if it passed the first check. If the paper met the requirements for further investigation, the paper was assessed by the other listed criteria. If not, the reason for the exclusion of the paper is shown in the last column. The papers that passed the first round check received a score for every criterion. The individual scores were added together, making the final score. The final score represents a number that shows how well the MM fits into this study. Papers that scored higher than 12 were included in the second selection. A threshold of 12 was applied to limit the MMs in this selection to a reasonable amount. It also ensured that the papers best suited to this research were included in the SLR. Therefore, all papers that score above 12 are colored in green and included in the second selection of SLR 1. This remaining set of papers comprises the second selection.

Table 19: First selection round of SLR 1

Nr.	Title	Author(s)	Date	Source	FC	A	T	D	O	SC	Additional information
				SCOPUS							
1	A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises	Schumacher, A., Erol, S., Sihna, W.	2016	Procedia CIRP	No						Assessment method, no MM present
2	A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)	Mittal, S., Khan, M.A., Romero, D., Wuest, T.	2018	Journal of Manufacturing Systems	No						Builds on the MM of Gökalp et al. (2017)
3	Three stage maturity model in SME's towards industry 4.0	Ganzarain, J., Errasti, N.	2016	Journal of Industrial Engineering and Management	Yes	3	3	2	1	9	
4	Smart Factory Implementation and Process Innovation	David R. Sjödin, Vinit Parida, Markus Leksell, and Aleksandar Petrovic	2018	Research Technology Management	Yes	4	2	5	5	16	
5	A maturity model for assessing the digital readiness of manufacturing companies	De Carolis, A., Macchi, M., Negri, E., Terzi, S.	2017	IFIP Advances in Information and Communication Technology	Yes	2	2	4	2	7	

6	Development of an assessment model for industry 4.0: Industry 4.0-MM	Gökalp, E., Şener, U., Eren, P.E.	2017	Communications in Computer and Information Science	Yes	4	2	4	4	15	
7	Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises	Schumacher, A., Nemeth, T., Sihn, W.	2017	Procedia CIRP	No						Assessment method, no MM present
8	An overview of a smart manufacturing system readiness assessment	Jung, K., Kulvatunyou, B., Choi, S., Brundage, M.P.	2016	IFIP Advances in Information and Communication Technology	Yes	1	2	1	2	6	Focus on processes
9	A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management	Caiado, R.G.G., Scavarda, L.F., Gavião, L.O., Nascimento, D.L.D.M., Garza-Reyes, J.A.	2021	International Journal of Production Economics	Yes	4	2	3	3	12	
10	Guiding Manufacturing Companies Towards Digitalization	Anna De Carolis, Marco Macchi, Elisa Negri, Sergio Terzi	2018	International Conference on Engineering, Technology and Innovation	Yes	2	2	3	2	9	
11	Contextualizing the outcome of a maturity assessment for Industry 4.0	Colli, M., Madsen, O., Berger, U., (...), Wæhrens, B.V., Bockholt, M.	2018	-	Yes	4	2	3	4	13	
12	Development of a Digitalization Maturity Model for the Manufacturing Sector	Canetta, L., Barni, A., Montini, E.		IEEE International Conference on Engineering, Technology and Innovation	No						Assessment method, no MM present
13	A Novel Methodology for Manufacturing Firms Value Modeling and Mapping to Improve Operational Performance in the Industry 4.0 era	Tonelli, F ,Demartini, M, Loleo, Testa, C	2016	Procedia CIRP	No						No MM present
14	Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice	Wagire, A.A., Joshi, R., Rathore, A.P.S., Jain, R.	2021	Production Planning and Control	Yes	2	2	1	3	8	
15	An Industry 4.0 maturity model proposal	Santos, R.C., Martinho, J.L.	2020	Journal of Manufacturing Technology Management	Yes	3	2	2	3	10	

16	Development of an Industry 4.0 maturity model for the delivery process in supply chains	Asdecker, B., Felch, V.	2018	Journal of Modelling in Management	Yes	2	2	4	3	11	Focus on logistics
17	SMEs maturity model assessment of IR4.0 digital transformation	Hamidi, S.R., Aziz, A.A., Shuhidan, S.M., Aziz, A.A., Mokhsin, M.	2018	Advances in Intelligent Systems and Computing	No						Assessment method, based on IMPULS model
18	Towards a smart manufacturing maturity model for SMEs (SM3E)	Mittal, S., Romero, D., Wuest, T.	2018	IFIP Advances in Information and Communication Technology	Yes	1	3	2	1	7	
19	An Industry 4.0 maturity model for machine tool companies	Rafael, L.D., Jaione, G.E., Cristina, L., Ibon, S.L.	2020	Technological Forecasting and Social Change	Yes	2	3	3	1	9	
20	Maturity Models and tools for enabling smart manufacturing systems: Comparison and reflections for future developments	De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M.P., Terzi, S.	2017	IFIP Advances in Information and Communication Technology	Yes	1	2	4	1	8	Focus on company procedures
21	To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises	Lin, T.-C., Wang, K.J., Sheng, M.L.	2020	International Journal of Computer Integrated Manufacturing	Yes	4	2	4	4	14	
22	Deriving essential components of lean and industry 4.0 assessment model for manufacturing SMEs	Kolla, S., Minufekr, M., Plapper, P.	2019	Procedia CIRP	No						No MM present
23	Human concepts and ergonomics in manufacturing in the industry 4.0 context – A scoping review	Reiman, A., Kaivo-oja, J., Parviainen, E., Takala, E.-P., Lauraeus, T.	2021	Technology in Society	No						No MM present, focus on human concepts
24	Assessing Industry 4.0 Maturity: An Essential Scale for SMEs	Trotta, D., Garengo, P.	2019	International Conference on Industrial Technology and Management	No						No MM present
25	Industry 4.0 readiness in Hungary: Model, and the first results in connection to data application	Nick, G., Szaller, Á., Bergmann, J., Várgedo, T.	2019	IFAC-PapersOnLine	No						Assessment method, no MM present
26	The development of the maturity model to evaluate the smart SMEs 4.0 readiness	Chonsawat, N., Sopadang, A.	2019	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						No MM present

27	SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration	Amaral, A., Peças, P.	2019	Computers in Industry	No						No MM present, focused on entry barriers
28	Striving for excellence in ai implementation: Ai maturity model framework and preliminary research results	Ellefsen, A.P.T., Oleśków-Szłapka, J., Pawłowski, G., Toboła, A.	2019	Logforum	Yes	3	3	1	1	8	Limited to Artificial Intelligence
29	Maturity models for digitalization in manufacturing - applicability for SMEs	Wiesner, S., Gaiardelli, P., Gritti, N., Oberti, G.	2018	IFIP Advances in Information and Communication Technology	No						No MM present
30	Dynamic capabilities for smart manufacturing transformation by manufacturing enterprises	Lin, T.-C., Sheng, M.L., Jeng Wang, K.	2020	Asian Journal of Technology Innovation	Yes	3	2	3	3	11	Focus on dimensions rather than MM
31	Production Assessment 4.0 – Concepts for the Development and Evaluation of Industry 4.0 Use Cases	Bauer, W., Pokorni, B., Findeisen, S.	2019	Advances in Intelligent Systems and Computing	No						Paper not available
32	The IoT technological maturity assessment scorecard: A case study of norwegian manufacturing companies	Jæger, B., Halse, L.L.	2017	IFIP Advances in Information and Communication Technology	Yes	4	2	4	4	14	
33	Industry 4.0 adoption key concepts: an empirical study on manufacturing industry	Narula, S., Prakash, S., Dwivedy, M., Talwar, V., Tiwari, S.P.	2020	Journal of Advances in Management Research	No						No MM present
34	Evaluating the smart maturity of manufacturing companies along the product development process to set a PLM project roadmap	Sassanelli, C., Rossi, M., Terzi, S.	2020	International Journal of Product Lifecycle Management	No						Paper not available
35	Change made in shop floor management to transform a conventional production system into an 'Industry 4.0': Case studies in SME automotive production manufacturing	Moica, S., Ganzarain, J., Ibarra, D., Ferencz, P.	2018	2018 7th International Conference on Industrial Technology and Management	No						MM that is used is already included in SLR
36	Indicators for maturity and readiness for digital forensic	Ariffin, K.A.Z., Ahmad, F.H.	2021	Computers and Security	Yes	1	2	2	1	6	

	investigation in era of industrial revolution 4.0										
37	Industry 4.0 Maturity and Readiness Models: A Systematic Literature Review and Future Framework	Hajoary, P.K.	2020	International Journal of Innovation and Technology Management	No						Paper not available
38	A Methodology to Assess the Skills for an Industry 4.0 Factory	Acerbi, F., Assiani, S., Taisch, M.	2019	IFIP Advances in Information and Communication Technology	No						Assessment method, focus on people management, no applicability in smart factory
39	Is a digital transformation framework enough for manufacturing smart products? The case of Small and Medium Enterprises	Zapata, M.L., Berrah, L., Tabourot, L.	2020	Procedia Manufacturing	No						Analysis of MMs
40	Evaluation of proceedings for SMEs to conduct I4.0 projects	Schmitt, P., Schmitt, J., Engelmann, B.	2020	Procedia CIRP	No						No MM present
41	Industry 4.0 in Practice-Identification of Industry 4.0 Success Patterns	Puchan, J., Zeifang, A., Leu, J.-D.	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	2	2	1	2	7	
42	Human resource practices accompanying industry 4.0 in European manufacturing industry	Vereycken, Y., Ramioul, M., Desiere, S., Bal, M.	2021	Journal of Manufacturing Technology Management	No						No MM present
43	Digital and social media marketing: A results-driven approach	Heinze, A., Fletcher, G., Rashid, T., Cruz, A.	2020	-	No						Book not available
44	Systematic literature review of industry 4.0 maturity model for manufacturing and logistics sectors	Angreani, L.S., Vijaya, A., Wicaksono, H.	2020	Procedia Manufacturing	No						Analysis of MMs
45	si3-Industry: A Sustainable, Intelligent, Innovative, Internet-of-Things Industry	Kumar, A., Nayyar, A.	2020	Advances in Science, Technology and Innovation	No						Analysis of MMs
46	Design of an assessment industry 4.0 maturity model: An	Azevedo, A., Santiago, S.B.	2019	Proceedings of the International Conference on Industrial Engineering	No						Assessment method, no MM present

	application to manufacturing company			and Operations Management							
47	Adoption of Factory of the Future Technologies	Biegler, C., Steinwender, A., Sala, A., Sihn, W., Rocchi, V.	2018	2018 IEEE International Conference on Engineering, Technology and Innovation	No						Impact indicator, no MM present
48	Data-driven manufacturing: An assessment model for data science maturity	Gökalp, M.O., Gökalp, E., Kayabay, K., Koçyiğit, A., Eren, P.E.	2021	Journal of Manufacturing Systems	Yes	1	2	4	2	9	MM within data science
49	Industry 4.0 readiness in manufacturing: Company Compass 2.0, a renewed framework and solution for Industry 4.0 maturity assessment	Nick, G., Kovács, T., Ko, A., Kádár, B.	2020	Procedia Manufacturing	No						Assessment method, no MM present
50	Cyber-physical systems with autonomous machine-to-machine communication: Industry 4.0 and its particular potential for purchasing and supply management	Schiele, H., Torn, R.-J.	2020	International Journal of Procurement Management	No						Assessment method, focus on MM for purchasing, no applicability in manufacturing
51	A method towards smart manufacturing capabilities and performance measurement	Xia, Q., Jiang, C., Yang, C., (...), Shuai, Y., Yuan, S.	2019	Procedia Manufacturing	Yes	4	2	3	4	13	
52	Need and Solution to Transform the Manufacturing Industry in the Age of Industry 4.0 – A Capability Maturity Index Approach	Stich, V., Gudergan, G., Zeller, V.	2018	IFIP Advances in Information and Communication Technology	No						No added value to the ACATECH MM
53	Different approaches of the PLM maturity concept and their use domains –analysis of the state of the art	Kärkkäinen, H., Silventoinen, A.	2016	IFIP Advances in Information and Communication Technology	No						Focus on analysis of product lifecycle management MMs, no applicability in manufacturing
54	A framework for assessing manufacturing smes industry 4.0 maturity	Amaral, A., Peças, P.	2021	Applied Sciences (Switzerland)	Yes	2	2	1	3	8	
55	Industry 4.0 Competence Maturity Model Design	Maisiri, W., Van Dyk, L.	2020	2020 IFEES World Engineering Education	No						Assessment model, no MM present

	Requirements: A Systematic Mapping Review			Forum - Global Engineering Deans Council							
56	Roadmap industry 4.0 - Implementation guideline for enterprises	Pessl, E., Sorko, S.R., Mayer, B.	2020	International Association for Management of Technology Conference	No						Focus on processes
57	Application of SIRI for Industry 4.0 Maturity Assessment and Analysis	Lin, W.D., Low, M.Y.H., Chong, Y.T., Teo, C.L.	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	2	2	3	3	10	
58	A Developed Analysis Models for Industry 4.0 toward Smart Power Plant System Process	Indrawan, H., Cahyo, N., Simaremare, A., Paryanto, P., Munyensanga, P.	2019	International Conference on Information and Communications Technology	Yes	4	2	2	4	12	
59	Agile requirement engineering maturity framework for industry 4.0	Elnagar, S., Weistroffer, H., Thomas, M.	2019	Lecture Notes in Business Information Processing	No						No MM present
60	A systematic literature review for industry 4.0 maturity modeling: state-of-the-art and future challenges	Elibal, K., Özceylan, E.	2021	Kybernetes	No						Assessment model, no MM present
61	Industry 4.0 maturity model assessing environmental attributes of manufacturing company	Zoubek, M., Poor, P., Broum, T., Basl, J., Simon, M.	2021	Applied Sciences	Yes	1	2	2	1	6	Limited to environmental research
62	Readiness and Maturity of Manufacturing Enterprises for Industry 4.0	Mrugalska, B., Stasiuk-Piekarska, A.	2020	Advances in Intelligent Systems and Computing	No						Focuses on analysis of several MMs
63	Towards a Novel Comparison Framework of Digital Maturity Assessment Models	Cognet, B., Pernot, J.-P., Rivest, L., Kärkkäinen, H., Lafleur, M.	2019	IFIP Advances in Information and Communication Technology	No						Focuses on analysis of two existing MMs
64	Implementation of interactive assistance systems by maturity models	Willeke, S., Kasselmann, S.	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	No						Paper not available
65	An effective architecture of digital twin system to support human decision making and AI-driven autonomy	Mostafa, F., Tao, L., Yu, W.	2021	Concurrency and Computation: Practice and Experience	Yes	2	2	5	5	14	Limited to data analytics, could be valuable in overall MM

66	Developing internet of things maturity model (IoT-MM) for manufacturing	Gaur, L., Ramakrishnan, R.	2020	International Journal of Innovative Technology and Exploring Engineering	Yes	2	2	2	4	10	
67	Industry 4.0 maturity assessment of the Banking Sector of Sri Lanka	Bandara, O.K.K., Tharaka, V.K., Wickramarachchi, A.P.R.	2019	IEEE International Research Conference on Smart Computing and Systems Engineering	Yes	2	1	3	3	8	
68	Radical change in machinery maintenance - A maturity model of maintenance using elements of industry 4.0	Poór, P., Ženíšek, D., Basl, J.	2019	Interdisciplinary Information Management Talks	No						Paper not available
69	Business analytics in Industry 4.0: A systematic review	Silva, A.J., Cortez, P., Pereira, C., Pilastri, A.	2021	Expert Systems	No						No MM present, focus on Business Analytics
70	A critical review of smart manufacturing and industry 4.0 maturity manufacturing & industry 4.0 maturity upstream industry	Onyeme, C., Liyanage, K.	2021	Advances in Transdisciplinary Engineering	No						Analysis of existing MMs, focus on the Oil and Gas industry
71	Selection Industry 4.0 maturity model using fuzzy and intuitionistic fuzzy TOPSIS concepts for a solar cell manufacturing company	Altan Koyuncu, C., Aydemir, E., Başarır, A.C.	2021	Soft Computing	No						Focus on decision making concepts for analysis of MMs. Limited to solar panel manufacturers.
72	A framework for a logistics 4.0 maturity model with a specification for internal logistics	Zoubek, M., Simon, M.	2021	MM Science Journal	Yes	1	2	3	2	7	
73	CCMS Model: A novel approach to digitalization level assessment for manufacturing companies	Nick, G., Szaller, Á., Várgedo, T.	2020	Proceedings of the 16th European Conference on Management Leadership and Governance	No						Assessment method, no clear MM levels present
74	Production Management as-a-Service: A Softbot Approach	Abner, B., Rabelo, R.J., Zambiasi, S.P., Romero, D.	2020	IFIP Advances in Information and Communication Technology	No						Functionalities of a chatbot on the shop floor, focus on production management

75	A critical review of maturity models in information technology and human landscapes on industry 4.0	Li, C.H., Lau, H.K.	2019	Proceedings of the IEEE International Conference on Industrial Technology	No						Analysis of existing MMs
76	Product lifecycle management maturity models in industry 4.0	dos Santos, K.C.P., de Freitas Rocha Loures, E., Junior, O.C., Santos, E.A.P.	2018	IFIP Advances in Information and Communication Technology	No						Analysis of existing MMs
77	Toward adaptive modelling & simulation for IMS: The adaptive capability maturity model and future challenges	Bril El Haouzi, H., Thomas, A., Charpentier, P.	2013	IFAC Proceedings Volumes	Yes	1	2	4	4	11	
78	Measuring the fourth industrial revolution through the Industry 4.0 lens: The relevance of resources, capabilities and the value chain	Castelo-Branco, I., Oliveira, T., Simões-Coelho, P., Portugal, J., Filipe, I.	2022	Computers in Industry							
79	The interplay between industry 4.0 maturity of manufacturing processes and performance measurement and management in SMEs	Naeem, H.M., Garengo, P.	2022	International Journal of Productivity and Performance Management	Yes	2	3	1	2	8	
80	Organizational process maturity model for IoT data quality management	Kim, S., Pérez-Castillo, R., Caballero, I., Lee, D.	2022	Journal of Industrial Information Integration	Yes	1	2	3	1	7	Focus on organisational processes
81	A non-intrusive Industry 4.0 retrofitting approach for collaborative maintenance in traditional manufacturing	García, Á., Bregon, A., Martínez-Prieto, M.A.	2022	Computers and Industrial Engineering	No						No MM present
82	Perspectives of Smart Factory Development and Maturity Model	Shvetsova, O.A., Levina, V.M., Kuzmina, A.D.	2022	Lecture Notes in Mechanical Engineering	No						No MM present
83	Industry 4.0 roadmap for SMEs: Validation of moderation techniques for creativity workshops	Brozzi, R., Rauch, E., Riedl, M., Matt, D.T.	2021	International Journal of Agile Systems and Management	No						Limited to roadmapping approaches
84	Steinlechner, M., Schumacher, A., Fuchs, B., Reichsthaler, L., Schlund, S.	Steinlechner, M., Schumacher, A., Fuchs, B., Reichsthaler, L., Schlund, S.	2021	Procedia CIRP	No						MM for employee competencies

85	Design of a business readiness model to realise a green industry 4.0 company	Benešová, A., Basl, J., Tupa, J., Steiner, F.	2021	International Journal of Computer Integrated Manufacturing	Yes	3	2	4	4	13	Limited to environmental research
86	A Model for Designing SMES' Digital Transformation Roadmap	Cunha, L., Sousa, C.	2021	Advances in Intelligent Systems and Computing	Yes	2	3	2	3	10	
87	Assessment of Organizational Capability for Data Utilization – A Readiness Model in the Context of Industry 4.0	Nausch, M., Schumacher, A., Sihn, W.	2020	Lecture Notes in Mechanical Engineering	Yes	1	2	3	2	8	
88	Development of production planning and control through the empowerment of artificial intelligence	Busch, M., Schuh, G., Kelzenberg, C., De Lange, J.	2019	International Conference on Artificial Intelligence for Industries	No						MM based on ACATECH model, focus on production planning
89	Evaluating the Smart Readiness and Maturity of Manufacturing Companies Along the Product Development Process	Sassanelli, C., Rossi, M., Terzi, S.	2019	IFIP Advances in Information and Communication Technology	Yes	1	2	2	1	6	
90	Smart manufacturing capability maturity model: Connotation, feature and trend	Peng, L., Feng, W., Chen, K., Li, C.	2016	Proceedings of the International Conference on Electronic Business (ICEB)	Yes	1	2	3	1	7	
91	Maturity model to promote the performance of collaborative business processes	Hachicha, M., Moalla, N., Fahad, M., Ouzrout, Y.	2016	IFIP Advances in Information and Communication Technology	Yes	1	2	2	1	6	Focus on development process
92	A systematic review of Industry 4.0 maturity models: applicability in the O&G upstream industry	Onyeme, C., Liyanage, K.	2022	World Journal of Engineering	No						Analysis of existing MMs
93	Towards an Information Systems-driven Maturity Model for Industry 4.0	Leotta, F., Mathew, J.G., Monti, F., Mecella, M.	2022	Lecture Notes in Business Information Processing	No						No MM present
94	A pilot study: An assessment of manufacturing SMEs using a new Industry 4.0 Maturity Model for Manufacturing Small- and Middle-sized Enterprises (I4MMSME)	Simetinger, F., Basl, J.	2022	Procedia Computer Science	No						No MM present

95	Implementation of I4.0 technologies in production systems: Opportunities and limits in the digital transformation	Facchini, F., Digiesi, S., Rodrigues Pinto, L.F.	2022	Procedia Computer Science	Yes	2	2	1	2	7	
96	A concept preview: Distributed Decision Making and Goal Execution	Simetinger, F.	2022	Procedia Computer Science	No						No MM present
97	Defining the Roadmap towards Industry 4.0: The 6Ps Maturity Model for Manufacturing SMEs	Spaltini, M., Acerbi, F., Pinzone, M., Gusmeroli, S., Taisch, M.	2022	Procedia CIRP	No						Assessment method, no MM present
98	The ECO Maturity Model - A human-centered Industry 4.0 maturity model	Bretz, L., Klinkner, F., Kandler, M., Shun, Y., Lanza, G.	2022	Procedia CIRP	Yes	1	2	2	1	6	Limited to environmental research
99	18th IFIP WG 5.1 International Conference on Product Lifecycle Management, PLM 2021	N.A.	2022	IFIP Advances in Information and Communication Technology	No						Book not available
100	Analysis of Cyber Security Features in Industry 4.0 Maturity Models	de Azambuja, A.J.G., Kern, A., Anderl, R.	2022	Lecture Notes in Computer Science	No						Analysis of existing MM
101	18th IFIP WG 5.1 International Conference on Product Lifecycle Management, PLM 2021	N.A.	2022	IFIP Advances in Information and Communication Technology	No						Already in SLR
102	Smart Factory in the Era of Fourth Industrial Revolution	Kossukhina, M.A., Shvetsova, O.A., Zaozerskaya, N.I.	2022	Lecture Notes in Mechanical Engineering	No						No MM present
103	Industry 4.0: The Case-Study of a Global Supply Chain Company	Honorato, C., de Melo, F.C.L.	2022	Lecture Notes in Mechanical Engineering	Yes	2	2	3	4	11	Focus on logistics
104	Development of an industry 4.0 competency maturity model	Maisiri, W., van Dyk, L., Coetzee, R.	2021	SAIEE Africa Research Journal	No						Assessment method, no MM present
105	Maturity model for industrial augmented reality | [Reifegradmodell für Industrial Augmented Reality]	Buchholz, K., Lehmann, L., Czarski, M.	2021	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	No						Paper not available
106	Holistic vision of tools for transformation towards Industry 4.0	Osorio, J.Z., De La Cruz, A.P.	2021	IEEE Colombian Conference on Communications and Computing	No						Analysis of existing MMs

107	Readiness Assessment of SMEs in Transitional Economies: Introduction of Industry 4.0	Suleiman, Z., Dikhanbayeva, D., Shaikholla, S., Turkyilmaz, A.	2021	ACM International Conference Proceeding Series	Yes	4	3	1	3	11	
108	Adoption of Digital Technologies During the COVID-19 Pandemic: Lessons Learned from Collaborative Academia-Industry R&D Case Studies	Simões, A., Ferreira, F., Castro, H., (...), Silva, D., Dalmarco, G.	2021	International Conference on Industrial Informatics	No						No MM present
109	Enabling Concepts of Digital Manufacturing Supply Chains: A Systematic Literature Review	Weerabahu, W.M.S.K., Samaranayake, P., Nakandala, D., Hurriyet, H.	2021	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	2	2	3	4	11	Focus on supply chain
110	A maturity model to assess the adoption of “Logistics 4.0” technologies in the 3PL industry	Baglio, M., Creazza, A., Dallari, F.	2021	Proceedings of the Summer School Francesco Turco	Yes	2	2	3	3	10	Focus on logistics
111	INDUSTRY 4.0 - ARTIFICIAL INTELLIGENCE (AI) CONTRIBUTION TO CAPABILITY MATURITY	Vermeulen, A., Pretorius, J.H.C., Viljoen, A.J.	2021	ASEM Virtual International Annual Conference "Engineering Management and The New Normal"	Yes	2	2	1	2	7	
112	CONTINUOUS IMPROVEMENT IT OPERATIONS IN BRAZIL: DEVELOPMENT OF AN INDICATOR MODEL FOR ASSESSING CONTINUOUS IMPROVEMENT IN INFORMATION TECHNOLOGY BASED ON LEAN SIX SIGMA	Honorato, W.J., Okano, M.T., Lobo, H., Viana, A.	2021	Proceedings of the 30th International Conference of the International Association for Management of Technology	No						No MM present
113	Towards a Pay-Per-X Maturity Model for Equipment Manufacturing Companies	Schroderus, J., Lasrado, L.A., Menon, K., Kärkkäinen, H.	2021	Procedia Computer Science	Yes	1	2	3	1	7	Focus on revenue model
114	Novel Maturity Model for Cybersecurity Evaluation in Industry 4.0	Kreppein, A., Kies, A., Schmitt, R.H.	2021	Communications in Computer and Information Science	No						Limited to cyber security, no MM present

115	3rd International Conference on Advances in Cyber Security, ACeS 2021	N.A.	2021	Communications in Computer and Information Science	No						Book not available
116	Digital maturity models: Comparing manual and semi-automatic similarity assessment frameworks	Cognet, B., Pernot, J.-P., Rivest, L., Danjou, C.	2021	International Journal of Product Lifecycle Management	No						Paper not available
117	BPM-D 2021 - Proceedings of the Best Dissertation Award, Doctoral Consortium, and Demonstration and Resources Track at BPM 2021, co-located with 19th International Conference on Business Process Management, BPM 2021	N.A.	2021	CEUR Workshop Proceedings	No						Book not available
118	Development of a Methodology to Analyze Implementation Patterns of Industry 4.0 Technologies	Quiroga, O., Osina, S., Díaz, M.	2021	Communications in Computer and Information Science	No						No MM present
119	Three Dimensional Technology Radar Model to Evaluate Emerging Industry 4.0 Technologies	Rauch, E., Vinante, E.	2021	Lecture Notes in Mechanical Engineering	Yes	2	2	2	5	10	
120	Literature review on maturity models for digital supply chains	Hellweg, F., Lechtenberg, S., Hellingrath, B., Thomé, A.M.T.	2021	Brazilian Journal of Operations and Production Management	No						Analysis of existing MMs
121	Review of research issues and challenges of maturity models concerning industry 4.0	Vijaya Kumar, N., Karadgi, S., Kotturshettar, B.B.	2020	IOP Conference Series: Materials Science and Engineering	Yes	4	2	2	5	13	
122	2nd International Conference on Materials Science and Manufacturing Technology	[No author name available]	2020	IOP Conference Series: Materials Science and Engineering	No						Conference not available
123	Design of Serious Simulation Games (SSG) as Learning Media for the Industry 4.0 Road Map in Indonesian Manufacturing	Suparno, A., Ardi, R.	2020	ACM International Conference Proceeding Series	No						Builds on the MM of ACATECH

124	A two-step digitalization level assessment approach for manufacturing companies	Schuh, G., Scheuer, T., Nick, G., Szaller, Á., Várgedo, T.	2020	Procedia Manufacturing	No							Builds on the MM of ACATECH
125	Developing a maturity model and an implementation plan for industry 4.0 integration	Melnik, S., Magnotti, M., Butts, C., Putman, C., Aqlan, F.	2020	Proceedings of the International Conference on Industrial Engineering and Operations Management	No							Builds on the MM of ACATECH
126	Intelligent Maintenance Maturity of Offshore Oil and Gas Platform: A Customized Assessment Model Complies with Industry 4.0 Vision	Duque, S.E., El-Thalji, I.	2020	Lecture Notes in Mechanical Engineering	No							Assessment model
127	Green industry 4.0 - Analysis of green aspects penetration in business readiness models for industry 4.0	Basl, J., Benesova, A.	2020	IDIMT 2020: Digitalized Economy, Society and Information Management	No							Paper not available
128	Introduction of autonomous production – a maturity model including recommended actions for manufacturing companies	Neumann, E.-C., Schumacher, S., Bauer, D., Lucht, T., Nyhuis, P.	2020	WT Werkstattstechnik	No							Paper not available
129	IT-Reifegradmodell für Fabriken: IT-Legacy-Strukturen für Industrie 4.0 harmonisieren	Sames, G.	2019	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	No							Paper not available
130	IDIMT 2019: Innovation and Transformation in a Digital World - 27th Interdisciplinary Information Management Talks	[No author name available]	2019	IDIMT 2019: Innovation and Transformation in a Digital World - 27th Interdisciplinary Information Management Talks	No							Book not available
131	2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings	[No author name available]	2018	IEEE International Conference on Engineering, Technology and Innovation	No							Book not available
132	Towards a platform for smart manufacturing improvement planning	Choi, S., Wuest, T., Kulvatunyou, B.S.	2018	IFIP Advances in Information and Communication Technology	No							No MM present

Grey literature											
142	Industry 4.0 Maturity Index	ACATECH; Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W.	2020		Yes	5	2	5	5	17	
143	IMPULS - Industrie 4.0 Readiness model	VDMA; K. Lichtblau, V. Stich, R. Bertenrath, M. Blum, M. Bleider, A. Millack, K. Schmitt, E. Schmitz, and M. Schröter,			Yes	2	2	2	3	9	
144	The Connected Enterprise Maturity Model	Rockwell Automation	2014		Yes	3	2	5	4	14	
145	Industry 4.0: Building the digital enterprise	Pwc; PricewaterhouseCoopers	2016		Yes	4	2	5	5	16	
146	Esko Digital Maturity Model	Esko	-		Yes	3	3	3	2	11	
147	Industrie 4.0 quo vadis?	Fraunhofer ISI	2020		Yes	5	2	3	5	15	
148	Smart Machine Maturity Model	Rockwell automation	2021		Yes	5	2	4	5	16	
149	Guideline Retrofit for Industrie 4.0	VDMA; Anderl, R., Picard, A., Wang, Y., Fleischer, J., Dosch, S., Klee, B., & Bauer, J.	2021		Yes	4	3	3	5	15	

11.3.2. SLR 2

Table 20: First selection round of SLR 2

Nr.	Title	Author(s)	Date	Source	FC	S	O	T	F	SC	Description
Scopus											
153	Value-VCA in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	2022	Journal of Manufacturing Technology Management	Yes	5	5	2	1	13	
154	A data-driven business model framework for VCA in Industry 4.0	Schaefer D., Walker J., Flynn J.,	2017	Advances in Transdisciplinary Engineering	Yes	5	4	2	1	12	
155	On the road to digital servitization – The (dis)continuous interplay between business model and digital technology	Chen Y., Visnjic I., Parida V., Zhang Z.,	2021	International Journal of Operations and Production Management	Yes	4	5	2	1	12	
156	Strategies for Digitalization in Manufacturing Firms	Björkdahl J.,	2020	California Management Review	Yes	1	2	2	1	6	

157	Digital transformation of business model in manufacturing companies: challenges and research agenda	Favoretto C., Mendes G.H.S., Filho M.G., Gouvea de Oliveira M., Ganga G.M.D.,	2022	Journal of Business and Industrial Marketing	Yes	4	5	2	1	12	
158	Revenue Models for Digital Servitization: A VCA Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	2021	IEEE Transactions on Engineering Management	Yes	4	5	2	1	12	
159	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	2018	Technological Forecasting and Social Change	Yes	3	5	3	2	13	
160	Increasing VCA by Enhancing Manufacturer Commitment - Designing a Value Cocreation System	Sakao T.,	2022	IEEE Engineering Management Review	Yes	2	2	2	1	7	
161	Resolving the productivity paradox of digitalised production	Dold L., Speck C.,	2021	International Journal of Production Management and Engineering	Yes	3	5	2	1	11	
162	How to use business model patterns for exploiting disruptive technologies	Echterfeld J., Amshoff B., Gausemeier J.,	2015	IAMOT 2015 - 24th International Association for Management of Technology Conference: Technology, Innovation and Management for Sustainable Growth, Proceedings	Yes	2	2	2	1	7	
163	Business Model Innovation for the Internet of Things	Deckert C., Kalefeld J., Kutz M.,	2022	Lecture Notes in Information Systems and Organisation	Yes	3	4	2	1	10	
164	Evaluation of Digital Business Model Opportunities: A Framework for Avoiding Digitalization Traps	Linde L., Sjödin D., Parida V., Gebauer H.,	2020	Research Technology Management	Yes	2	4	2	1	9	
165	Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	4	4	2	2	12	
166	Circular disruption: Digitalisation as a driver of circular economy business models	Neligan A., Baumgartner R.J., Geissdoerfer M., Schöggl J.-P.,	2022	Business Strategy and the Environment	Yes	2	1	2	1	6	

167	Filling the void of family leadership: institutional support to business model changes in the Italian Industry 4.0 experience	Cucculelli M., Dileo I., Pini M.,	2022	Journal of Technology Transfer	No						Focus on external variables to support hypotheses, no VCA present
168	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	2021	Journal of Business Research	Yes	4	3	2	3	12	
169	How AI capabilities enable business model innovation: Scaling AI through co-evolutionary processes and feedback loops	Sjödin D., Parida V., Palmié M., Wincent J.,	2021	Journal of Business Research	Yes	3	4	2	3	12	
170	Modeling language for value networks	Schneider M., Mittag T., Gausemeier J.,	2016	IAMOT 2016 - 25th International Association for Management of Technology Conference, Proceedings: Technology - Future Thinking	Yes	2	4	2	1	9	
171	Impacts on business models resulting from digitalization	Simoes A.C., Rodrigues J.C., Ribeiro S.,	2021	2021 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2021 - Proceedings	Yes	3	3	3	1	10	
172	The impact of digitalization and additive manufacturing on business models and value chains: A scoping review	van Heerden A., Grobbelaar S.S., Sacks N.,	2020	Towards the Digital World and Industry X.0 - Proceedings of the 29th International Conference of the International Association for Management of Technology, IAMOT 2020	Yes	5	5	2	1	13	
173	Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	2019	Journal of Manufacturing Technology Management	Yes	3	5	3	1	12	
174	Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	2021	Electronic Markets	Yes	4	4	2	3	13	

175	Networked business models for current and future road freight transport: taking a truck manufacturer’s perspective	Lind F., Melander L.,	2021	Technology Analysis and Strategic Management	Yes	4	3	3	1	11	
176	Employee qualification in the smart factory: Starting points on the need for qualifications of employees based on novel business models of a smart factory [Mitarbeiterqualifikation in der Smart Factory: Ansatzpunkte zum Qualifizierungsbedarf der Mitarbeiter ausgehend von neuartigen Geschäftsmodellen einer Smart Factory]	Herzog S., Sanders A., Redlich T., Wulfsberg J.,	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	No						Paper is about employee qualification in business models rather than VCA
177	Leveraging the value from digitalization: a business model exploration of new technology-based firms in vertical farming	Thomson L.,	2022	Journal of Manufacturing Technology Management	Yes	3	3	1	1	8	
178	On the move towards customer-centric business models in the automotive industry - a conceptual reference framework of shared automotive service systems	Grieger M., Ludwig A.,	2019	Electronic Markets	Yes	4	3	3	1	11	
179	23rd International Conference on Business Information Systems, BIS 2020	[No author name available],	2020	Lecture Notes in Business Information Processing	No						Book with various subjects. VCA and industry 4.0 not in same subject
180	How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	2022	California Management Review	Yes	4	5	2	3	14	
181	The Influence of Critical Concepts on Business Model at a Smart Factory: A Case Study	Jerman A., Erenda I., Bertoncelj A.,	2019	Business Systems Research	No						Focus on concepts that influence business models in a smart factory
182	Methodology for Digitalization - A Conceptual Model	Ng H.Y., Tan P.S., Lim Y.G.,	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	3	2	2	1	8	
183	Water 4.0: An Integrated Business Model from an Industry 4.0 Approach	Alabi M.O., Telukdarie A., Van Rensburg N.J.,	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	3	3	1	1	8	Literature review on water 4.0

184	Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	2019	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2019	Yes	4	5	2	1	12	
185	Developing a construction business model transformation canvas	Das P., Perera S., Senaratne S., Osei-Kyei R.,	2020	Engineering, Construction and Architectural Management	Yes	4	3	2	1	10	
186	Evaluating the New AI and Data Driven Insurance Business Models for Incumbents and Disruptors: Is there Convergence?	Zarifis A., Cheng X.,	2021	Business Information Systems	Yes	3	3	2	2	10	
187	Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	2022	Industrial Marketing Management	Yes	4	4	2	2	12	
188	A Business Model Strategy Analysis of the Additive Manufacturing Consulting Industry	Bugdahn, M., Rogers, H., Pawar, K.S.,	2019	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation	No						Topic is on additive manufacturing
189	Digital communication channels in industry 4.0 implementation: The role of internal communication [Digitalni komunikacijski kanali u implementaciji industrije 4.0: Uloga interne komunikacije]	Kovaitė K., Šūmakaris P., Stankevičienė J.,	2020	Management (Croatia)	Yes	2	2	2	1	7	
190	Platform-based servitization and business model adaptation by established manufacturers	Tian J., Coreynen W., Matthyssens P., Shen L.,	2021	Technovation	Yes	4	3	2	2	11	
191	How the industrial internet of things changes business models in different manufacturing industries	Arnold C., Kiel D., Voigt K.-I.,	2021	Digital Disruptive Innovation	Yes	2	1	2	2	7	
192	E-commerce in industry 4.0	Gao X., Xu J.,	2021	E-business In The 21st Century: Essential Topics And Studies (Second Edition)	No						Focus on e-commerce
193	The digitalization and servitization of manufacturing: A review on digital business models	Luz Martín-Peña M., Díaz-Garrido E., Sánchez-López J.M.,	2018	Strategic Change	Yes	3	3	2	1	9	

194	Internet of things and original design manufacturing business model: Case study of COSMAX	Park Y.W., Hong P., Shin G.C.,	2019	PICMET 2019 - Portland International Conference on Management of Engineering and Technology: Technology Management in the World of Intelligent Systems, Proceedings	Yes	3	2	1	1	7	
195	From Heron of Alexandria to Amazon's Alexa: a stylized history of AI and its impact on business models, organization and work	Fanti L., Guarascio D., Moggi M.,	2022	Journal of Industrial and Business Economics	No						
196	The implementation of digital technologies for operations management: a case study for manufacturing apps	Zangiacomi A., Oesterle J., Fornasiero R., Sacco M., Azevedo A.,	2017	Production Planning and Control	Yes	3	3	2	1	9	
197	Digital business model innovation: Implications for offering, platform and organization	Simonsson J., Magnusson M.,	2018	Digital Business Models: Driving Transformation and Innovation	Yes	4	4	3	1	12	
198	Designing the business model of an energy Datahub	Küfeoğlu S., Üçler Ş.,	2021	Electricity Journal	No						Focus on digital technologies to be used in energy distribution, which has another focus as BM in smart manufacturing
199	How the industrial internet of things changes business models in different manufacturing industries	Arnold C., Kiel D., Voigt K.-I.,	2016	International Journal of Innovation Management	Yes	4	3	2	1	10	
200	How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	2020	Industrial Marketing Management	Yes	4	5	2	2	13	
201	From managing customers to joint venturing with customers: co-creating service value in the digital age	Falkenreck C., Wagner R.,	2022	Journal of Business and Industrial Marketing	Yes	4	2	1	1	8	

202	The digital twin – A critical enabler of industry 4.0	Ohnemus T.,	2020	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	Yes	4	3	2	3	12	
203	Smart circular product design strategies towards eco-effective production systems: A lean eco-design industry 4.0 framework	Dahmani N., Benhida K., Belhadi A., Kamble S., Elfezazi S., Jauhar S.K.,	2021	Journal of Cleaner Production	No						Focus on circular business models, no VCA discussed
204	Spanish SMEs' digitalization enablers: E-Receipt applications to the offline retail market	Gavrila Gavrila S., de Lucas Ancillo A.,	2021	Technological Forecasting and Social Change	Yes	3	2	1	1	7	
205	Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective	Frank A.G., Mendes G.H.S., Ayala N.F., Ghezzi A.,	2019	Technological Forecasting and Social Change	Yes	3	2	2	1	8	
206	Leveraging industry 4.0 – A business model pattern framework	Weking J., Stöcker M., Kowalkiewicz M., Böhm M., Krcmar H.,	2020	International Journal of Production Economics	Yes	4	4	2	1	11	
207	A maturity framework for autonomous solutions in manufacturing firms: The interplay of technology, ecosystem, and business model	Thomson L., Kamalaldin A., Sjödin D., Parida V.,	2022	International Entrepreneurship and Management Journal	Yes	2	2	2	1	7	
208	Modeling IoT and big data implementation	Jonny, Kriswanto, Toshio M.,	2021	Proceedings of 2021 International Conference on Information Management and Technology, ICIMTech 2021	Yes	2	2	2	1	7	
209	Change made in shop floor management to transform a conventional production system into an 'Industry 4.0': Case studies in SME automotive production manufacturing	Moica S., Ganzarain J., Ibarra D., Ferencz P.,	2018	2018 7th International Conference on Industrial Technology and Management, ICITM 2018	No						Focus is on a MM and implementation of technologies
210	Business models for sustainable innovation in industry 4.0: Smart manufacturing processes, digitalization of production systems, and data-driven decision making	Ludbrook F., Michalikova K.F., Musova Z., Suler P.,	2019	Journal of Self-Governance and Management Economics	Yes	3	3	2	1	9	
211	Service-oriented business models in manufacturing in the digital ERA: Toward a new taxonomy	Aas T.O.R.H., Breunig K.J., Hellström M.M., Hydle K.M.,	2020	International Journal of Innovation Management	Yes	4	5	2	1	12	

212	Two archetypes of business model innovation processes for manufacturing firms in the context of digital transformation	Rummel F., Hüsig S., Steinhauser S.,	2022	R and D Management	No						Topic is about BM development processes
213	Industrie 4.0 by siemens: Steps made next	Cozmiuc D., Petrisor I.,	2018	Journal of Cases on Information Technology	Yes	4	4	2	2	12	
214	The impact of COVID-19 on the grocery retail industry: innovative approaches for contactless store concepts in Germany	Heins C.,	2022	Foresight	No						Business models of B2C, focused on Covid-19
215	Digital dark matter within product service systems	Vendrell-Herrero F., Myrthianos V., Parry G., Bustinza O.F.,	2017	Competitiveness Review	Yes	3	1	2	1	7	
216	Smart spare parts management systems in semiconductor manufacturing	Zheng M., Wu K.,	2017	Industrial Management and Data Systems	Yes	4	2	2	2	10	
217	Perception of value delivered in digital servitization	Simonsson J., Agarwal G.,	2021	Industrial Marketing Management	No						Focus on relationship between IEO and adoption, no VCA within I4.0
218	How digitalized interactive platforms create new value for customers by integrating B2B and B2C models? An empirical study in China	He J., Zhang S.,	2022	Journal of Business Research	No						Another topic as industry 4.0
219	Industrial value chain research and applications for industry 4.0	Yacout S.,	2019	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						No VCA present
220	Organizing the development of digital product-service platforms	Simonsson J., Magnusson M., Johanson A.,	2020	Technology Innovation Management Review	No						Focus on challenges of BM implementation
221	Siemens' customer value proposition for the migration of legacy devices to cyber-physical systems in industrie 4.0	Cozmiuc D.C., Petrisor I.I.,	2018	Analyzing the Impacts of Industry 4.0 in Modern Business Environments	Yes	4	2	2	1	9	
222	Strategizing in a digital world: Overcoming cognitive barriers, reconfiguring routines and introducing new organizational forms	Volberda H.W., Khanagha S., Baden-Fuller C., Mihalache O.R., Birkinshaw J.,	2021	Long Range Planning	No						Another topic as VCA within industry 4.0
223	Dynamics of long-life assets: The editors' intro	Granholm G., Grösser S.N., Reyes-Lecuona A.,	2017	Dynamics of Long-Life Assets: From Technology Adaptation to Upgrading the Business Model	Yes	2	1	2	1	6	

224	How can machine tool builders VCA value from smart services? Avoiding the service and digitalization paradox	Kamp B., Zabala K., Zubiaurre A.,	2022	Journal of Business and Industrial Marketing	Yes	3	2	2	1	8	
225	Assessing the value of data an approach to evaluate the technology driven benefits of smart product data	Schuh G., Kreutzer R., Patzwald M.,	2017	PICMET 2017 - Portland International Conference on Management of Engineering and Technology: Technology Management for the Interconnected World, Proceedings	Yes	4	4	2	2	12	
226	Smart Services Maturity Level in Germany	Kaltenbach F., Marber P., Gosemann C., Bolts T., Kuhn A.,	2018	2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings	Yes	2	3	2	2	9	
227	A production bounce-back approach in the Cloud manufacturing network: case study of COVID-19 pandemic	Shahab E., Kazemisaboor A., Khaleghparast S., Fatahi Valilai O.,	2022	International Journal of Management Science and Engineering Management	Yes	2	2	2	1	7	
228	Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	2020	26th International Association for Management of Technology Conference, IAMOT 2017	Yes	5	4	2	2	13	
229	Cyber-physical systems as field of action [Handlungsfeld Cyber-Physische Systeme]	Reinhart G., Klöber-Koch J., Braunreuther S.,	2016	ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb	Yes	2	3	2	2	9	
230	A PARADIGM SHIFT IN BUSINESS MANAGEMENT IN THE CONTEXT OF INDUSTRY 4.0	Gorelikov K.A., Komarov A.V., Bezsmertnaya E.R.,	2021	Advances in Research on Russian Business and Management	Yes	4	4	2	2	12	
231	Artificial intelligence in operations management and supply chain management: an exploratory case study	Helo P., Hao Y.,	2021	Production Planning and Control	Yes	4	3	2	3	12	Focus on AI
232	Possible changes of Industry 4.0 in 2030 in the face of uberization: Results of a participatory and systemic foresight study	Bootz, J.-P., Michel, S., Pallud, J., Monti, R.	2022	Technological Forecasting and Social Change	Yes	2	3	3	1	9	

233	Industry 4.0 technologies: critical success concepts for implementation and improvements in manufacturing companies	Pozzi R., Rossi T., Secchi R.,	2021	Production Planning and Control	Yes	2	3	2	1	8	
234	Chasing the Crowd: Digital Transformations and the Digital Driven System Design Paradigm	Ivanov I.I.,	2019	Lecture Notes in Business Information Processing	No						Another topic as VCA
235	Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal	Nascimento D.L.M., Alencastro V., Quelhas O.L.G., Caiado R.G.G., Garza-Reyes J.A., Lona L.R., Tortorella G.,	2019	Journal of Manufacturing Technology Management	No						Focus on circular economy
236	The digital transformation of industrial players	Danuso A., Giones F., Ribeiro da Silva E.,	2022	Business Horizons	Yes	1	3	2	1	7	
237	Disrupted HR?	Minbaeva D.,	2021	Human Resource Management Review	Yes	2	3	1	1	7	Applications in HR and Covid-19
238	Future research avenues at the nexus of circular economy and digitalization	Burmaoglu S., Ozdemir Gungor D., Kirbac A., Saritas O.,	2022	International Journal of Productivity and Performance Management	No						Focus on Circular economy and minimal VCA present
239	Cyber-physical smart manufacturing systems: Sustainable industrial networks, cognitive automation, and data-centric business models	Tuffnell C., Kral P., Siekelova A., Horak J.,	2019	Economics, Management, and Financial Markets	Yes	3	4	2	1	10	
240	A model for plant digitalisation, simulation and improvement: A case study in the automotive tier one supplier	Cortes D., Ramirez J., Villagomez L.E., Batres R., Molina A., Velilla A., Lozano G., Gonzalez E., Puente J., Esparza G., Cruz N.,	2019	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2019	Yes	1	3	2	1	7	
241	Industrial Policy: A New Reality in the Context of Digital Transformation of the Economy	Romanova O.A., Kuzmin E.,	2021	Lecture Notes in Information Systems and Organisation	No						Focus on regulation
242	Rethinking Software Development for Collaboration Technologies	Eisentrager, M., Adler, S., Fischer, E.	2019	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation	No						no VCA present

243	Implementation of AI in Business Models: A Conceptual Study	Drave V.A., Rahman A., Drave J.K., Kumar S., Sharma G.M., Lai K.K.,	2021	Proceedings of the International Conference on Industrial Engineering and Operations Management	Yes	2	2	2	3	9	
244	Artificial intelligence and business models in the sustainable development goals perspective: A systematic literature review	Di Vaio A., Palladino R., Hassan R., Escobar O.,	2020	Journal of Business Research	No						Focus is on the role of AI in developing BMs
245	The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization	Kohtamäki M., Parida V., Patel P.C., Gebauer H.,	2020	Technological Forecasting and Social Change	Yes	5	4	2	1	12	
246	How Digital Shadows, New Forms of Human-Machine Collaboration, and Data-Driven Business Models Are Driving the Future of Industry 4.0: A Delphi Study	Piller, F.T., Nitsch, V.	2022	Contributions to Management Science	Yes	2	3	2	1	8	
247	IEEE International Conference on Industrial Engineering and Engineering Management	[No author name available],	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	4	3	1	1	9	
248	Big data analytics in industry 4.0: Sustainable industrial VCR, manufacturing process innovation, and networked production structures	Gradeck J., Neguriță O., Grecu I., Grecu G.,	2019	Journal of Self-Governance and Management Economics	Yes	4	4	2	1	11	
249	Digitization in the Market for Entrepreneurial Finance: Innovative Business Models and New Financing Channels	Bertoni F., Bonini S., Capizzi V., Colombo M.G., Manigart S.,	2021	Entrepreneurship: Theory and Practice	Yes	1	4	1	1	7	Focus on Finance sector
250	Additive manufacturing technologies and business models – a systematic literature review	Florén H., Barth H., Gullbrand J., Holmén M.,	2021	Journal of Manufacturing Technology Management	No						Focus on Additive manufacturing, which is not in the MM
251	Applying IIoT and AI - Opportunities, requirements and challenges for industrial machine and equipment manufacturers to expand their services	Qvist-Sørensen P.,	2020	Central European Business Review	Yes	2	2	2	2	8	
252	Challenges and opportunities in breakthrough development in global markets	Kruglyakova V., Meshcheryakova M., Sereda E., Hvostikova V., Titova M.,	2019	Proceedings of the 33rd International Business Information Management Association Conference,	Yes	1	2	2	1	6	

				IBIMA 2019: Education Excellence and Innovation Management through Vision 2020								
253	Networked information-driven technologies for cyber-physical system-based smart manufacturing	Keane E.,	2019	Journal of Self-Governance and Management Economics	Yes	3	3	2	1	9	
254	State of Industry 4.0 Across Six French Companies	Chengula Z., Morato M.A.R., Thurner T., Wiedensohler Y., Martin L.,	2018	2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings	Yes	1	2	2	1	6	
255	What do we know about "industry 4.0" so far?	Kiel D.,	2020	26th International Association for Management of Technology Conference, IAMOT 2017	Yes	1	2	2	1	6	
256	From concept to the introduction of industry 4.0	Crnjac M., Veža I., Banduka N.,	2017	International Journal of Industrial Engineering and Management	Yes	2	2	2	1	7	
257	Industry 4.0, digitization, and opportunities for sustainability	Ghobakhloo M.,	2020	Journal of Cleaner Production	Yes	2	2	2	1	7	
258	Resilient cyber-physical systems and big data architectures in industry 4.0: Smart digital factories, automated production systems, and innovative sustainable business models	Nica E., Potcovaru A.-M., Hurdubei Ionescu R.E.,	2019	Economics, Management, and Financial Markets	Yes	1	1	2	1	5	
259	Global manufacturing value networks: assessing the critical roles of platform ecosystems and Industry 4.0	Das A., Dey S.,	2021	Journal of Manufacturing Technology Management	Yes	2	3	2	1	8	
260	3rd Annual International Scientific Conference on Digital Transformation in Industry: Trends, Management, Strategies, DTI 2021	[No author name available]	2022	Lecture Notes in Information Systems and Organisation	No						Proceeding contain 33 papers, which keywords do not appear in the same paper
261	Development and Validation of Industry 4.0 Readiness Scale - A Formative Model	Hajoary P.K.,	2021	International Journal of Innovation and Technology Management	Yes	1	3	2	1	7	

262	Procurement 4.0 and the fourth industrial revolution: The opportunities and challenges of a digital world	Nicoletti B.,	2020	Procurement 4.0 and the Fourth Industrial Revolution: The Opportunities and Challenges of a Digital World	Yes	4	4	2	1	11	
263	The effects of inter- and intraorganizational concepts on the adoption of electronic booking systems in the maritime supply chain	Zeng F., Chan H.K., Pawar K.,	2021	International Journal of Production Economics	No						Focus on e-booking systems
264	Modeling manufacturer's capabilities for the Internet of Things	Hasselblatt M., Huikkola T., Kohtamäki M., Nickell D.,	2018	Journal of Business and Industrial Marketing	No						Focus on capabilites
265	Artificial intelligence techniques for a scalable energy transition: Advanced concepts, digital technologies, decision support tools, and applications	Sayed-Mouchaweh M.,	2020	Artificial Intelligence Techniques for a Scalable Energy Transition: Advanced Concepts, Digital Technologies, Decision Support Tools, and Applications	Yes	4	4	2	2	12	
266	Industry 4.0 - Integration strategies for small and medium-sized enterprises	Müller J.M., Voigt K.-I.,	2020	26th International Association for Management of Technology Conference, IAMOT 2017	No						No VCA described
267	The rise of robotics & AI: Technological advances & normative dilemmas	Pagallo U., Corrales M., Fenwick M., Forgó N.,	2018	Perspectives in Law, Business and Innovation	Yes	3	3	2	2	10	
268	Transformational shifts through digital servitization	Tronvoll B., Sklyar A., Sörhammar D., Kowalkowski C.,	2020	Industrial Marketing Management	Yes	2	3	2	1	8	
269	Where Digitalization Meets Sustainability: Opportunities and Challenges	Aksin-Sivrikaya S., Bhattacharya C.B.,	2017	CSR, Sustainability, Ethics and Governance	Yes	2	2	2	1	7	
270	Advanced manufacturing technology adoption and innovation: A systematic literature review on barriers, enablers, and innovation types	Stornelli A., Ozcan S., Simms C.,	2021	Research Policy	No						Focus on barriers to enablers
271	A method for analyzing practicing managers' perception on the disruptive nature of digitalization in machine-building industry	Sommarberg M., Mäkinen S.J.,	2017	PICMET 2017 - Portland International Conference on Management of	Yes	2	2	2	1	7	

				Engineering and Technology: Technology Management for the Interconnected World, Proceedings							
272	THE PLATFORMISATION OF MANUFACTURING: TOWARDS A HOLISTIC PERSPECTIVE FOR SYSTEMATISING DIGITAL MANUFACTURING PLATFORMS	Lerch C.M., Heimberger H.,	2022	International Journal of Innovation Management	Yes	3	4	1	3	11	
273	Digital twin for manufacturing equipment in industry 4.0	Moreno T., Almeida A., Ferreira F., Caldas N., Toscano C., Azevedo A.,	2021	Advances in Transdisciplinary Engineering	Yes	2	3	2	3	10	
274	5th International Conference on Digital Economy, ICDEc 2020	[No author name available],	2020	Lecture Notes in Business Information Processing	Yes	4	4	2	3	13	
275	Analysis and synthesis of Industry 4.0 research landscape: Using latent semantic analysis approach	Wagire A.A., Rathore A.P.S., Jain R.,	2020	Journal of Manufacturing Technology Management	No						No VCA mentioned, business models only mentioned once
276	Rethinking Industry 4.0: Is there life beyond manufacturing?	Ferrás-Hernández X.,	2020	International Journal of Business Environment	No						No VCA mentioned
277	Reflection of digital transformation on corporate sustainability and a theoratical perspective	Zehir C., Özgül B.,	2019	Handbook of Research on Strategic Fit and Design in Business Ecosystems	Yes	2	4	2	1	9	Focus on sustainability
278	Exploring 3D printing technology in the context of product-service innovation: Case study of a business venture in south of France	Marić J.,	2020	International Journal of Business Environment	No						Focus on additive manufacturing, which is not included in the MM
279	17th International Conference on Perspectives in Business Informatics Research, BIR 2018	[No author name available],	2018	Lecture Notes in Business Information Processing	Yes	2	2	2	1	7	
280	Amalgamation of 3D printing technology and the digitalized industry – Development and evaluation of an open innovation business process model	Warnecke D., Gevorkjan G.D., Teuteberg F.,	2018	Lecture Notes in Business Information Processing	No						Topic is business process management
281	INDUSTRY 4.0: AN OVERVIEW	Nwasuka N.C., Nwaiwu U., Princewill N.C.,	2022	Proceedings on Engineering Sciences	No						No VCA present

282	What can we learn from digitalisation and servitisation to shape a new mobility paradigm?	Goehlich V., Fournier G., Richter A.,	2020	International Journal of Business and Globalisation	Yes	3	3	2	1	9	
283	Strategic investment decision-making: Mergers and acquisitions toward industry 4.0	Alkaraan F.,	2021	Advances in Mergers and Acquisitions	No						No VCA present
284	A Self-Tuning Model for Smart Manufacturing SMEs: Effects on Digital Innovation	Del Giudice, M., Scuotto, V., Papa, A., (...), Bresciani, S., Warkentin, M.	2021	Journal of Product Innovation Management	No						Topic is on exploring relationships, n no VCA present
285	The Growing Role of FinTech and Robo-advisors	Cull M.,	2022	De Gruyter Handbook of Personal Finance	Yes	2	3	1	3	9	Focus on Finance
286	THE IMPORTANCE OF THE SMART MANUFACTURING DESIGN AT 4.0 INDUSTRIAL VISION IN STREET ECONOMY	Yildirim M.,	2020	Contemporary Studies in Economic and Financial Analysis	Yes	2	4	2	1	9	
287	Driving concepts of digital transformation for manufacturing enterprises: a multi-case study from China	Wang Y., Su X.,	2021	International Journal of Technology Management	Yes	2	4	2	2	10	
288	Development of maturity model for assessing the implementation of Industry 4.0: learning from theory and practice	Wagire A.A., Joshi R., Rathore A.P.S., Jain R.,	2021	Production Planning and Control	Yes	1	3	2	1	7	
289	Application of blockchain and smart contracts in autonomous vehicle supply chains: An experimental design	Arunmozhi M., Venkatesh V.G., Arisian S., Shi Y., Raja Sreedharan V.,	2022	Transportation Research Part E: Logistics and Transportation Review	Yes	2	5	1	3	11	No blockchain discussed in MM
290	Providing industry 4.0 technologies: The case of a production technology cluster	Dalmarco G., Ramalho F.R., Barros A.C., Soares A.L.,	2019	Journal of High Technology Management Research	No						no VCA discussed
291	8th International Conference on Decision Support System Technology, ICDSST 2022	[No author name available],	2022	Lecture Notes in Business Information Processing	No						Book which uses keywords in different sections
292	Business analytics in manufacturing: Current trends, challenges and pathway to market leadership	Omar Y.M., Minoufekr M., Plapper P.,	2019	Operations Research Perspectives	Yes	4	4	2	1	11	
293	A method for anticipating the disruptive nature of digitalization in the machine-building industry	Sommarberg M., Mäkinen S.J.,	2019	Technological Forecasting and Social Change	No	2	4	2	1	9	

294	Navigating disruptive crises through service-led growth: The impact of COVID-19 on Italian manufacturing firms	Rapaccini M., Saccani N., Kowalkowski C., Paiola M., Adrodegari F.,	2020	Industrial Marketing Management	No						Focus on Covid-19 recovery
295	How do manufacturing companies and service providers share knowledge in the context of servitization? An evolutionary-game model of complex networks	Ma, R., Jiang, L., Wang, T., Wang, X., Ruan, J.	2022	International Journal of Production Research	Yes	3	4	2	1	10	
296	The case for health 4.0	Thuemmler C.,	2017	Health 4.0: How Virtualization and Big Data are Revolutionizing Healthcare	Yes	3	3	1	1	8	Focus on Health sector
297	Initial overview of industry 4.0 in textile companies from Santa Catarina	Falani L.A., De Aguiar C.R.L., Dal Forno A.J.,	2021	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						Topic is barriers
298	It takes two to tango: technological and non-technological concepts of Industry 4.0 implementation in manufacturing firms	Črešnar R., Dabić M., Stojčić N., Nedelko Z.,	2022	Review of Managerial Science	No						no VCA present
299	Agile requirement engineering maturity framework for industry 4.0	Elnagar S., Weistroffer H., Thomas M.,	2019	Lecture Notes in Business Information Processing	No						No VCR present, only mentioned BM
300	Industry 4.0 desiderata as micro foundations in the assessment of companies' maturity-Case study	Nogalski B., Niewiadomski P.,	2020	Management and Production Engineering Review	No						Another topic as VCA
301	Research Anthology on Changing Dynamics of Diversity and Safety in the Workforce	[No author name available]	2021	Research Anthology on Cross-Industry Challenges of Industry 4.0	Yes	1	2	2	2	7	
302	On sustainable production networks for industry 4.0	Prause G., Atari S.,	2017	Entrepreneurship and Sustainability Issues	Yes	2	3	2	1	8	
303	Digital transformation: Toward new research themes and collaborations yet to be explored	Talafidaryani M., Jalali S.M.J., Moro S.,	2021	Business Information Review	No						Another topic as VCA
304	Industrie 4.0 by siemens: Steps made today	Cozmiuc D., Petrisor I.,	2018	Journal of Cases on Information Technology		1	3	2	3	9	
305	Specialized business incubators as a strategy for small and medium-sized enterprises in the industry 4.0 era – a systemic approach	Bosques-Brugada G., Mendoza-Del Villar L.A., Oliva-López E.,	2020	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						Another topic as industry 4.0 or VCA, focus on business incubators

		Garza-Reyes J.A., Tupa J.,									
306	Introduction: Supply chain integration challenges in the commercial aviation industry	Richter K., Witt N.,	2016	Supply Chain Integration Challenges in Commercial Aerospace: A Comprehensive Perspective on the Aviation Value Chain	No						Another topic as industry 4.0
307	Possibilities for applying the circular economy in the aerospace industry: Practices, opportunities and challenges	Rodrigues Dias V.M., Jugend D., de Camargo Fiorini P., Razzino C.D.A., Paula Pinheiro M.A.,	2022	Journal of Air Transport Management	No						Topic is circular economy, with less focus on industry 4.0 and manufacturing
308	The impact of the collaborative robot on competitive priorities: Case study of an automotive supplier [O impacto do robô colaborativo nas prioridades competitivas: Estudo de caso em um fornecedor automotivo]	Vido M., Scur G., Massote A.A., Lima F.,	2021	Gestao e Producao	No						Another topic as industry 4.0
309	Value logics for service innovation: practice-driven implications for service-dominant logic	Lindhult E., Chirumalla K., Oghazi P., Parida V.,	2018	Service Business	No						Another topic as industry 4.0
310	Manufacturing Execution System Selection by Use of Multicriteria Partial Information Method	Mondadori J.A.P., Belderrain M.C.N., Ferreira R.J.P., Françozo R.V.,	2021	Lecture Notes in Business Information Processing	Yes	3	3	3	1	10	
311	Asset replacement in the context of Servitization	Amadi-Echendu J., Dakada M., Ramlal R., Englebrecht F.,	2019	2019 IEEE Technology and Engineering Management Conference, TEMSCON 2019	Yes	4	4	1	1	10	
312	The industrial management of SMEs in the era of Industry 4.0	Moeuf A., Pellerin R., Lamouri S., Tamayo-Giraldo S., Barbaray R.,	2018	International Journal of Production Research	Yes	3	3	3	2	11	
313	Component suppliers in the commodity battle: Can digital technology in multi-tier supply chains help to transform liabilities into opportunities?	Herbst, T.D.	2021	International Journal of Business Science and Applied Management	Yes	4	4	3	3	14	

314	The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0	Culot G., Orzes G., Sartor M., Nassimbeni G.,	2020	Technological Forecasting and Social Change	Yes	2	3	2	1	8	
315	The potentials of augmented reality in supply chain management: a state-of-the-art review	Rejeb A., Keogh J.G., Wamba S.F., Treiblmaier H.,	2021	Management Review Quarterly	No						Topic is augmented reality, which is not part of the MM
316	Industry 4.0: A Korea perspective	Sung T.K.,	2018	Technological Forecasting and Social Change	Yes	2	2	2	1	7	
317	Challenges in the development of smart production machines in the context of the PGE - Product Generation Engineering model [Herausforderungen bei der Entwicklung von smarten Produktionsmaschinen im Kontext des Modells der PGE - Produktgenerationsentwicklung]	Albers A., Basedow G.N., Spadinger M., Raab F., Chen J., Stürmlinger T.,	2019	Stuttgarter Symposium fur Produktentwicklung	Yes	2	3	2	1	8	
318	The impact of digital technologies on vocational education and training needs: An exploratory study in the German food industry	Achtenhagen C., Achtenhagen L.,	2019	Education and Training	No						Topic is about the perspective on employee qualifications
319	Mapping of PSS research: A bibliometric analysis	Khan M.A., Wuest T.,	2018	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						Does only focus on statistics and do not provide valuable content
320	Digital transformation in family-owned Mittelstand firms: A dynamic capabilities perspective	Soluk J., Kammerlander N.,	2021	European Journal of Information Systems	Yes	2	3	3	1	9	
321	An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	2020	Journal of Cleaner Production	Yes	3	4	2	3	12	
322	Patterns of digitalisation in machinery-building industries: Evidence from Russia	Turovets Y., Vishnevskiy K.,	2019	Engineering Management in Production and Services	Yes	2	3	2	1	8	
323	Open innovation in the manufacturing industry: A review and research agenda	Obradović T., Vlačić B., Dabić M.,	2021	Technovation	Yes	2	2	2	1	7	
324	Digital transformation in manufacturing	Holzhauser K., Schalla P.,	2016	The Palgrave Handbook of Managing Continuous Business Transformation	Yes	4	4	2	1	11	
325	Digital Innovation: Creating Competitive Advantages	Berawi M.A., Suwartha N., Asvial	2020	International Journal of Technology	Yes	3	3	2	1	9	

		M., Harwahyu R., Suryanegara M., Setiawan E.A., Surjandari I., Zagloel T.Y.M., Maknun I.J.,									
326	Digital ecosystem structure formation depending on the archetype of distribution network participants	Krasyuk I.A., Kolgan M.V., Medvedeva Y.,	2022	European Journal of Management and Business Economics	Yes	2	2	1	1	6	
327	9th International Conference on Exploring Service Science, IESS 2018	[No author name available],	2018	Lecture Notes in Business Information Processing	No						Book with 30 papers which do not imply all keywords in one paper, book not available
328	Design of smart connected manufacturing resources to enable changeability, reconfigurability and total-cost-of-ownership models in the factory-of-the-future	Brad S., Murar M., Brad E.,	2018	International Journal of Production Research	No						Topic is about changeability and reconfigurability into resources
329	Key performance concepts for integration of Industry 4.0 and sustainable supply chains: a perspective of Indian manufacturing industry	Gopal P.R.C., Kadari P., Thakkar J.J., Mawandiya B.K.,	2022	Journal of Science and Technology Policy Management	No						Topic is about key performance indicator, no focus on VCA
330	Internet-of-Things and Cloud Computing for Smart Industry: A Systematic Mapping Study	Breivold H.P.,	2017	Proceedings - 2017 5th International Conference on Enterprise Systems: Industrial Digitalization by Enterprise Systems, ES 2017	No						A systematic mapping study
331	Industry 4.0 Maturity and Readiness Models: A Systematic Literature Review and Future Framework	Hajoary P.K.,	2020	International Journal of Innovation and Technology Management	No						Focus on MMs, already assessed in SLR 1
332	Role of Enabling Technologies in Soft Tissue Engineering: A Systematic Literature Review	Sood S.K., Rawat K.S., Sharma G.,	2022	IEEE Engineering Management Review	Yes	2	3	2	1	8	
333	The influence of additive manufacturing on early internationalization: considerations into potential avenues of IE research	Hannibal M.,	2020	Journal of International Entrepreneurship	No						Topic is Additive manufacturing, which is not part of the MM

334	Three stage maturity model in SME's towards industry 4.0	Ganzarain J., Errasti N.,	2016	Journal of Industrial Engineering and Management	No						Focus on MM, no VCA present, already assessed in SLR 1
335	1st Indian International Conference on Industrial Engineering and Operations Management, IEOM 2021	[No author name available],	2021	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						Proceeding containing 122 papers, which do not imply all keywords in one paper
336	Review of information systems research for media industry–recent advances, challenges, and introduction of information systems research in the media industry	Lugmayr A., Grueblbauer J.,	2017	Electronic Markets	Yes	2	3	1	1	7	Focus on digitalization in media sector
337	Guest editorial: Industrial services – The solution provider's stairway to heaven or highway to hell?	Kohtamäki M., Helo P.,	2015	Benchmarking	Yes	3	5	2	1	11	
338	Tailored automotive business strategies in the context of digitalization and service-oriented models	Kompalla A., Geldmacher W., Just V., Lange S.,	2017	Quality - Access to Success	No						Does not focus on industry 4.0, but on digitalization in automotive such as car sharing
339	HR 4.0 case studies	Krishnaveni D., Mansurali A., Harish V.,	2020	Innovations and Challenges in Human Resource Management for HR4.0	No						Topic is people management
340	5G in digital supply chain and operations management: fostering flexibility, end-to-end connectivity and real-time visibility through internet-of-everything	Dolgui A., Ivanov D.,	2022	International Journal of Production Research	Yes	2	3	2	3	10	
341	Impact of digital transformation on the automotive industry	Llopis-Albert C., Rubio F., Valero F.,	2021	Technological Forecasting and Social Change	No						No focus on Industry 4.0
342	Fabrication laboratories: The development of new business models with new digital technologies	Santos G., Murmura F., Bravi L.,	2018	Journal of Manufacturing Technology Management	No						Topic is about digital laboratories, no industry 4.0 or VCA
343	Collaborations for Digital Transformation: Case Studies of Industry 4.0 in Brazil	Rocha C., Quandt C., Deschamps F., Philbin S., Cruzara G.,	2021	IEEE Transactions on Engineering Management	No						Topic is on R&D collaboration with business partners

344	A topic-based patent analytics approach for exploring technological trends in smart manufacturing	Wang J., Hsu C.-C.,	2021	Journal of Manufacturing Technology Management	Yes	1	1	2	1	5	
345	Incorporating service design for industry 4.0: A scientometric review for green and digital transformation driven by service design	Jiang X.,	2020	Proceedings - 2020 Management Science Informatization and Economic Innovation Development Conference, MSIEID 2020	Yes	2	2	2	1	7	
346	Towards understanding the impact of industry 4.0 technologies on operational performance: an empirical investigation in the US and EU automotive industry	Nader J., Mezher M.A., El-Khalil R.,	2021	Proceedings of the International Conference on Industrial Engineering and Operations Management	No						No VCA present
347	Integration of ontologies to support Control as a Service in an Industry 4.0 context	Lyu M., Biennier F., Ghodous P.,	2021	Service Oriented Computing and Applications	No						No VCA present
348	How does performance vary between early and late adopters of Industry 4.0? A qualitative viewpoint	Antony J., Sony M., McDermott O., Furterer S., Pepper M.,	2021	International Journal of Quality and Reliability Management	Yes	1	4	2	1	8	
349	Impacts of the Implementation of Industry´s 4.0 Technologies in the Portuguese Textile Industry: The Effect of Management and Leadership Practices on Implementation of Industry s 4.0 Technologies	Almeida A., Melo P.N., Conceição O.,	2021	Proceedings of the 17th European Conference on Management, Leadership and Governance, ECMLG 2021	Yes	1	2	2	1	6	
350	Technology selection for industry 4.0 digital transformation: A decision-making model combining AHP, QFD and MIP	Erbay H., Yıldırım N.,	2019	Managing Technology for Inclusive and Sustainable Growth - 28th International Conference for the International Association of Management of Technology, IAMOT 2019	Yes	3	4	3	1	11	
351	Traceability and transparency in supply chain management system of pharmaceutical goods through block chain	Srivastava S., Bhadauria A., Dhaneshwar S., Gupta S.,	2019	International Journal of Scientific and Technology Research							Topic is blockchain, which is not part of the MM
352	After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	2022	Manufacturing and Service Operations Management	Yes	2	5	2	3	12	

353	Multi-objective optimization of costs and energy efficiency associated with autonomous industrial processes for sustainable growth	Rubio F., Llopis-Albert C., Valero F.,	2021	Technological Forecasting and Social Change	Yes	3	4	2	1	10	
354	Recent progress towards photovoltaics' circular economy	Rabaia, M.K.H., Semeraro, C., Olabi, A.-G.	2022	Journal of Cleaner Production	Yes	1	3	2	1	7	
355	Exploring the value of IoT data as an enabler of the transformation towards servitization: an action design research approach	Chen K.-L., Lassen A., Li C., Møller C.,	2022	European Journal of Information Systems	Yes	2	2	2	1	7	
356	Understanding the paradigm shift in maritime education: The role of 4th Industrial Revolution technologies: an industry perspective	Simmons E., McLean G.,	2020	Worldwide Hospitality and Tourism Themes	No						Topic is education of maritime employees
357	Requirements for designing and controlling autonomous collaborative robots system-an industrial case	Hanna A., Götvall P.-L., Ekström M., Bengtsson K.,	2018	Advances in Transdisciplinary Engineering	No						Focus on automation and robotics, no VCA present
358	A Conceptual Framework for Applying Artificial Intelligence in Project Management	Auth G., Johnk J., Wiecha D.A.,	2021	Proceedings - 2021 IEEE 23rd Conference on Business Informatics, CBI 2021 - Main Papers	Yes	4	2	2	3	11	
359	Initial Empirical Evidence on How Jordanian Manufacturing Smes Cope With The COVID-19 Pandemic	Al-Hyari K.,	2020	Academy of Strategic Management Journal	No						Topic is on applying digitalization for Covid-19, not industry 4.0
360	Digitalization of manufacturing execution systems: The core technology for realizing future smart factories	Demartini M., Tonelli F., Damiani L., Revetria R., Cassettari L.,	2017	Proceedings of the Summer School Francesco Turco	Yes	3	4	2	3	12	
361	Industry Commons: an ecosystem approach to horizontal enablers for sustainable cross-domain industrial innovation (a positioning paper)	Magas, M., Kiritsis, D.	2022	International Journal of Production Research	No						No VCA present
362	Modelling Production Workflows in Automotive Manufacturing	Konig S., Vogel-Heuser B., Fieg E., Hahn M., Kopp O.,	2021	Proceedings - 2021 IEEE 23rd Conference on							Another topic as industry 4.0, focus on BPMN

				Business Informatics, CBI 2021 - Main Papers							
363	What drives industry 4.0 adoption? An examination of technological, organizational, and environmental determinants	Arnold C., Veile J.W., Voigt K.-I.,	2018	Towards Sustainable Technologies and Innovation - Proceedings of the 27th Annual Conference of the International Association for Management of Technology, IAMOT 2018	No						No VCA present
364	IM2, a maturity model for innovation in SMEs	Igartua J.I., Retegi J., Ganzarain J.,	2018	Direccion y Organizacion	Yes	2	4	3	1	10	
365	Digital transformation strategy framework	Saleh A., Awny M.M.,	2020	Towards the Digital World and Industry X.0 - Proceedings of the 29th International Conference of the International Association for Management of Technology, IAMOT 2020	No						Topic is on executing digialization strategy projects, no VCR
366	Making or breaking the business case of digital transformation initiatives: the key role of learnings	Colli M., Stingl V., Waehrens B.V.,	2022	Journal of Manufacturing Technology Management	Yes	3	4	2	1	10	
367	First Steps for a 5G-Ready Service in Cloud Manufacturing	Burow K., Hribernik K., Thoben K.-D.,	2018	2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings	Yes	3	4	2	2	11	
368	‘Avatar journey mapping’ for manufacturing firms to reveal smart-service opportunities over the product life-cycle	West S., Stoll O., Mueller-Csernetzky P.,	2020	International Journal of Business Environment	No						Another topic as industry 4.0
369	Implementing IoT for the detection of production machine failures	Badwelan A., Alatefi M., Ghaleb A.M., Alsamhan A.M.,	2019	Proceedings of the International Conference on Industrial Engineering and Operations Management	Yes	3	3	2	3	11	
370	Industrial IoT integrated with simulation -A digital twin approach to support real-time decision making	Santos, R., Basto, J., Alcalá, S.G.S.,	2019	Proceedings of the International Conference on	Yes	2	4	2	3	11	

		Frazzon, E., Azevedo, A.		Industrial Engineering and Operations Management							
371	Adaptive scheduling in the era of cloud manufacturing	Mourtzis D.,	2020	International Series in Operations Research and Management Science	Yes	2	4	2	1	9	
372	A Framework for Enabling Cyber-Twins based Industry 4.0 Application Development	Bamunuarachchi D., Georgakopoulos D., Jayaraman P.P., Banerjee A.,	2021	Proceedings - 2021 IEEE International Conference on Services Computing, SCC 2021	Yes	4	3	2	3	12	
373	Aiding observational ergonomic evaluation concepts using MOCAP systems supported by AI-based posture recognition	Igelmo V., Syberfeldt A., Högberg D., García Rivera F., Pérez Luque E.,	2020	Advances in Transdisciplinary Engineering	No						Another topic as industry 4.0 and no VCA present
374	Influence of artificial intelligence (AI) on firm performance: the business value of AI-based transformation projects	Wamba-Taguimdje S.-L., Fosso Wamba S., Kala Kamdjoug J.R., Tchatchouang Wanko C.E.,	2020	Business Process Management Journal	No						Explores the relationship between AI and firm performance, no VCA discussed
375	Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers	Stentoft J., Adsbøll Wickstrøm K., Philipsen K., Haug A.,	2021	Production Planning and Control	No						Discussed barriers and drivers towards industry 4.0, No VCA discussed
376	A Perspective for the Implementation of a Path Towards the Factory of the Future: The Italian Case	Zangiacomi A., Sacco M., Pessot E., De Zan A., Bertetti M.,	2018	2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings	Yes	2	4	3	1	10	
377	Modelling of sharing networks in the circular economy	Jayakumar J., K J., K.E.K V., Hasibuan S.,	2020	Journal of Modelling in Management	No						Focus on B2C sharing networks in circular economy
378	Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	2018	PICMET 2018 - Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The	Yes	4	4	3	2	13	

				Engine for Economic Growth, Proceedings							
379	A Review of the Concepts, Applications, and Challenges of Adopting Artificial Intelligence in the Property Assessment Office	Cusack, M., Quintos, C., Foster, K., (...), Horne, T., McCluskey, W.	2022	Journal of Property Tax Assessment and Administration	No						No VCA present
380	Quality 4.0: leveraging Industry 4.0 technologies to improve quality management practices – a systematic review	Saihi A., Awad M., Ben-Daya M.,	2021	International Journal of Quality and Reliability Management	Yes	4	4	2	1	11	
381	AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	2022	Decision Support Systems	Yes	3	5	3	3	14	
382	Design and development of automobile assembly model using federated artificial intelligence with smart contract	Manimuthu A., Venkatesh V.G., Shi Y., Sreedharan V.R., Koh S.C.L.,	2022	International Journal of Production Research	Yes	3	5	2	3	13	
383	MULTI-CRITERIA DIGITALIZATION OPPORTUNITY ANALYSIS (DOPA) WITH SAW AND FUZZY AHP: A CASE STUDY ON CNC CUTTING PROCESS IMPROVEMENT	Siyahi B.T., Özbek O., Yildirim N., Kahya A.S., AhiOğlu İ.,	2021	Proceedings of the 30th International Conference of the International Association for Management of Technology, IAMOT 2021 - MOT for the World of the Future	No						No VCA present
384	The significance of employee behaviours and soft management practices to avoid digital waste during a digital transformation	Alieva, J., Powell, D.J.	2022	International Journal of Lean Six Sigma	No						Focus is on relationship between several variables, no VCA present
385	BLOCKCHAIN TECHNOLOGY AND DIGITAL SUPPLY CHAINS: TOWARDS REVOLUTIONIZING THE INDUSTRY OF THE FUTURE	Alabi M., Telukdarie A.,	2021	2021 ASEM Virtual International Annual Conference	No						Topic is on blockchain, which is not part of the MM
386	Emerging technologies in Indian mining industry: an exploratory empirical investigation regarding the adoption challenges	Bhattacharyya S.S., Shah Y.,	2022	Journal of Science and Technology Policy Management	Yes	1	2	1	1	5	

387	New IoT proximity service based heterogeneous RFID readers collision control	Tamayo Segarra J.I., Jammal B.A., Chaouchi H.,	2017	PSU Research Review	No						Technical paper of the use of RFID
388	Business Logistics Optimization Using Industry 4.0: Current Status and Opportunities	Surajit B., Telukdarie A.,	2019	IEEE International Conference on Industrial Engineering and Engineering Management	Yes	3	2	2	1	8	
389	Maintenance in aeronautics in an industry 4.0 context: The role of ar and am	Ceruti A., Marzocca P., Liverani A., Bil C.,	2018	Advances in Transdisciplinary Engineering	No						Topic is augmented reality and additive manufacturing, which are not part of the MM
390	Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant, L., Forsyth, A., Farcas, R., (...), Fan, I.-S., Shehab, E.	2021	Advances in Transdisciplinary Engineering	Yes	3	4	2	3	12	
391	Industry 4.0 and the circular economy: A literature review and recommendations for future research	Awan U., Sroufe R., Shahbaz M.,	2021	Business Strategy and the Environment	Yes	3	3	2	1	9	
392	The mark of industry 4.0: how managers respond to key revolutionary changes	Yunus E.N.,	2020	International Journal of Productivity and Performance Management	Yes	1	1	2	1	5	
393	Developing a learning-to-learn capability: insights on conditions for Industry 4.0 adoption	Saabye H., Kristensen T.B., Wæhrens B.V.,	2021	International Journal of Operations and Production Management	No						Focus is on learn-to-learn capabilities, no VCA present
394	Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant L., Forsyth A., Farcas R., Voigtländer M., Singh S., Fan I.-S., Shehab E.,	2021	Advances in Transdisciplinary Engineering	No						No VCA present
395	Developing Strategies and Current Trend of Smart Factory	Jeong B., Bang J.-Y.,	2018	Journal of International Logistics and Trade	No						Focus on managerial perspective
396	Moving towards digitalization: a multiple case study in manufacturing	Zangiacomi, A., Pessot, E., Fornasiero, R., Bertetti, M., Sacco, M.	2020	Production Planning and Control	No						No VCA present
397	An Overview of Smart Manufacturing for Competitive and Digital Global Supply Chains	Menon S., Shah S., Coutroubis A.,	2018	2018 IEEE International Conference on Technology Management, Operations	No						No VCA present

				and Decisions, ICTMOD 2018							
398	Logistics 4.0 measurement model: empirical validation based on an international survey	Dallasega P., Woschank M., Sarkis J., Tippayawong K.Y.,	2022	Industrial Management and Data Systems	No						No VCA present
399	Factory automation and information technology convergence in complex manufacturing	Fan I.-S., Oswin L.,	2016	Advances in Transdisciplinary Engineering	Yes	2	2	2	1	7	
400	A new management approach based on Additive Manufacturing technologies and Industry 4.0 requirements	Patalas-Maliszewska J., Topczak M.,	2021	Advances in Production Engineering And Management	No						Topic is additive manufacturing, which is not part of the MM
401	How to implement industry 4.0? An empirical analysis of lessons learned from best practices	Veile, J.W., Kiel, D., Müller, J.M., Voigt, K.-I.	2018	Towards Sustainable Technologies and Innovation - Proceedings of the 27th Annual Conference of the International Association for Management of Technology	Yes	1	2	2	1	6	
402	A guideline of quality steps towards zero defect manufacturing in industry	Eleftheriadis R.J., Myklebust O.,	2016	Proceedings of the International Conference on Industrial Engineering and Operations Management	Yes	3	4	2	1	10	
403	Trust in the Context of Home Office and Digitalization: Evaluation of a Trust Model Within New Contexts	Bolzern-Konrad B.,	2021	Proceedings of the 17th European Conference on Management, Leadership and Governance, ECMLG 2021	No						Topic is home offices
404	Artificial Intelligence Adoption in the Post COVID-19 New-Normal and Role of Smart Technologies in Transforming Business: a Review	Agarwal P., Swami S., Malhotra S.K.,	2022	Journal of Science and Technology Policy Management	Yes	1	2	1	3	7	
Grey literature											
406	Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	2020	-	Yes	4	4	3	1	12	

407	Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	2020	-	Yes	5	5	3	1	14	
408	Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	2017	-	Yes	4	4	2	3	13	

11.4. Appendix 4: Second selection round

Table 21: Second selection round for SLR 2

Nr.	Title	Author(s)/Institution	Sc	Included/excluded	Reason for exclusion
180	How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	14	Included	
313	Component suppliers in the commodity battle: Can digital technology in multi-tier supply chains help to transform liabilities into opportunities?	Herbst, T.D.	14	Excluded	Focus on strategic opportunities by component suppliers, but do not provide concrete ways to VCA value.
381	AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	14	Included	
407	Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	14	Included	
153	Value-VCA in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	13	Included	
159	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	13	Included	
172	The impact of digitalization and additive manufacturing on business models and value chains: A scoping review	van Heerden A., Grobbelaar S.S., Sacks N.,	13	Excluded	Paper is not accessible

174	Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	13	Included	
200	How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	13	Included	
228	Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	13	Included	
274	5th International Conference on Digital Economy, ICDEc 2020	[No author name available],	13	Excluded	Focuses on the process towards business models, so-called business model innovation. Does not provide insights into existing business models that could be useful for OEMs.
378	Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	13	Included	
382	Design and development of automobile assembly model using federated artificial intelligence with smart contract	Manimuthu A., Venkatesh V.G., Shi Y., Sreedharan V.R., Koh S.C.L.,	13	Excluded	Smart contracting linked to blockchain applications, in which the latter is not part of the MM. No use-cases for smart machining.
408	Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	13	Included	
154	A data-driven business model framework for VCA in Industry 4.0	Schaefer D., Walker J., Flynn J.,	12	Included	
155	On the road to digital servitization – The (dis)continuous interplay between business model and digital technology	Chen Y., Visnjic I., Parida V., Zhang Z.,	12	Excluded	Only describes VCR for the Computerization phase. No value capturing present.
157	Digital transformation of business model in manufacturing companies: challenges and research agenda	Favoretto C., Mendes G.H.S., Filho M.G., Gouvea de Oliveira M., Ganga G.M.D.,	12	Excluded	Topic is about challenges that exist for value capturing in industry 4.0. Does not provide ways to overcome these.
158	Revenue Models for Digital Servitization: A VCA Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	12	Included	Paper does not focus on business models itself, but provides design principles that have to be kept in mind when developing. This paper is included because of the valuable insights into business model customization.

165	Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	12	Included	
168	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	12	Included	
169	How AI capabilities enable business model innovation: Scaling AI through co-evolutionary processes and feedback loops	Sjödin D., Parida V., Palmié M., Wincent J.,	12	Excluded	Topic is on AI business model innovation, which provides data pipeline capabilities. Hence, this paper is not focusing on VCA
173	Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	12	Included	Value capturing present, no detailed information
184	Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	12	Included	
187	Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	12	Included	
197	Digital business model innovation: Implications for offering, platform and organization	Simonsson J., Magnusson M.,	12	Exclude	
202	The digital twin – A critical enabler of industry 4.0	Ohnemus T.,	12	Excluded	Paper not accessible
211	Service-oriented business models in manufacturing in the digital ERA: Toward a new taxonomy	Aas T.O.R.H., Breunig K.J., Hellström M.M., Hydle K.M.,	12	Included	
213	Industrie 4.0 by siemens: Steps made next	Cozmiuc D., Petrisor I.,	12	Excluded	Mentions BM in the abstract once, but does not discuss BMs in the full-text
225	Assessing the value of data an approach to evaluate the technology driven benefits of smart product data	Schuh G., Kreutzer R., Patzwald M.,	12	Excluded	Does not provide VCA information for industry 4.0.

230	A PARADIGM SHIFT IN BUSINESS MANAGEMENT IN THE CONTEXT OF INDUSTRY 4.0	Gorelikov K.A., Komarov A.V., Bezsmertnaya E.R.,	12	Excluded	Paper not accessible
231	Artificial intelligence in operations management and supply chain management: an exploratory case study	Helo P., Hao Y.,	12	Excluded	Focus is on SCM and not on OEMs. Also no value capturing present.
245	The relationship between digitalization and servitization: The role of servitization in capturing the financial potential of digitalization	Kohtamäki M., Parida V., Patel P.C., Gebauer H.,	12	Excluded	Investigates the relationship between digitalization, servitization and financial performance. Does not provide concrete ways to VCA value from industry 4.0.
265	Artificial intelligence techniques for a scalable energy transition: Advanced concepts, digital technologies, decision support tools, and applications	Sayed-Mouchaweh M.,	12	Excluded	Book with multiple titles. None of the titles describe value capturing for OEMs. This book is technologically oriented with a focus on the energy transition.
321	An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	12	Included	
352	After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	12	Included	
360	Digitalization of manufacturing execution systems: The core technology for realizing future smart factories	Demartini M., Tonelli F., Damiani L., Revetria R., Cassettari L.,	12	Excluded	Does not provide value capturing.
372	A Framework for Enabling Cyber-Twins based Industry 4.0 Application Development	Bamunuarachchi D., Georgakopoulos D., Jayaraman P.P., Banerjee A.,	12	Excluded	Paper is technologically oriented with an use-case, but does not provide value capturing.
390	Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant, L., Forsyth, A., Farcas, R., (...), Fan, I.-S., Shehab, E.	12	Included	
405	Digital servitization business models in ecosystems: a theory of the firm	Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H. and Baines, T.	12	Excluded	Builds on the business models of paper 187, which is already included in SLR 2. Hence, paper 187 is included since it is more recent and it adds extra relevance.
406	Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	12	Included	

11.5. Appendix 5: Third selection round

Although all papers from Scopus were already peer-reviewed, a final check was executed to secure the quality of this study. Therefore, a quality check was executed only with the fourth selection of literature. In this case, multiple quality metrics were used in a logical order. A reason for this is that the databases used in the SLR do not have a single consistent method for assessing papers. In addition, some papers or journals in the SLR could not be Captured by one metric.

First of all, the quality of the paper itself was leading. Therefore, the Scopus Paper Quartile Metric P% was used. This metric explains how the paper performs against similar papers in a particular category by citation benchmarking. Hence, the higher the percentile, the higher the paper score in citation benchmarking. For example, the 99th percentile indicates that an article is in the top 1% globally (Scopus, 2020). P% is divided into four percentiles Q1, Q2, Q3, and Q4. The second quartile Q2 represents above average, whereas Q3 is below average. The limit for exclusion of a paper is below Q3, which states that the paper performs below 75% globally. However, some papers in Scopus were not ranked and the individual score of the paper could not be assessed. Therefore, measures are done that assess the journal in which the paper is published. This indicates the overall quality of the papers that were published in that particular journal. The quality of the journal could be assessed by the internal impact concepts CiteScore J% from Scopus and the internal metric Journal Impact Factor JIF from Web of Science. Both calculate the number of citations of a journal over a certain period of time, and compare it to the number of same document types that are published during that same time period. The only difference is that J% holds a period of four years into account, while the JIF uses the previous two years. Sci Journal published a list of average impact concepts for each category (W., J., 2022). This research took the impact concepts of the Computer Science category as a benchmark for all the papers in the second selection round. Therefore, the average score in the category of Computer Science is 2.96, which is the threshold between middle and low scores. The limit for exclusion of a paper is below an impact score of 1. If the quality of the paper P% is above the limit, the quality of the journal J% and JIF were not considered.

Table 22: Indicators for quality assessment

Priority	1	2	3
Database	Scopus Paper Quartile Metric	Scopus Journal CiteScore	Web of Science - Journal Impact Factor
Abbreviation	P%	J%	JIF
High	Q1 (>75th)	>10	>10
Medium	Q2 (50th-75th)	2.9-10	2.9-10
Low	Q3 (25th-50th)	1-2.9	1-2.9
Limit	Q4 (<25th)	<1	<1

11.5.1. SLR 1

Table 23: Third selection round scores for SLR 1

Nr.	Title	Author	Journal	P%	J%	JIF
4	Smart Factory Implementation and Process Innovation	David R. Sjödin, Vinit Parida, Markus Leksell, and Aleksandar Petrovic	Research Technology Management	Q1	4.7	2.9
6	Development of an assessment model for industry 4.0: Industry 4.0-MM	Gökalp, E., Şener, U., Eren, P.E.	Communications in Computer and Information Science	Q1	-	-
152	SIMMI 4.0 - A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0	Leyh, C., Bley, K., Schäffer, T., & Forstenhäusler, S.	2016 Federated Conference on Computer Science and Information Systems (FedCSIS)	Q1	-	-
150	Maturity Model for Data Driven Manufacturing (M2DDM)	Weber, C., Königsberger, J., Kassner, L., & Mitschang, B.	Sustainability	-	-	3.9
21	To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises	Lin, T.-C., Wang, K.J., Sheng, M.L.	International Journal of Computer Integrated Manufacturing	Q1	7.2	4.4
32	The IoT technological maturity assessment scorecard: A case study of norwegian manufacturing companies	Jæger, B., Halse, L.L.	IFIP Advances in Information and Communication Technology	Q1	1.2	-
65	An effective architecture of digital twin system to support human decision making and AI-driven autonomy	Mostafa, F., Tao, L., Yu, W.	Concurrency and Computation: Practice and Experience	Q1	3.8	1.8
2	A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)	Mittal, S., Khan, M.A., Romero, D., Wuest, T.	Journal of Manufacturing Systems	Q1	15	9.5
11	Contextualizing the outcome of a maturity assessment for Industry 4.0	Colli, M., Madsen, O., Berger, U., Wæhrens, B.V., Bockholt, M.	-	Q1	-	-
46	Design of an assessment industry 4.0 maturity model: An application to manufacturing company	Azevedo, A., Santiago, S.B.	Proceedings of the International Conference on Industrial Engineering and Operations Management	Q1	-	-
51	A method towards smart manufacturing capabilities and performance measurement	Xia, Q., Jiang, C., Yang, C., Shuai, Y., Yuan, S.	Procedia Manufacturing	Q1	-	-
85	Design of a business readiness model to realise a green industry 4.0 company	Benešová, A., Basl, J., Tupa, J., Steiner, F.	International Journal of Computer Integrated Manufacturing	Q2	7.2	4.4
121	Review of research issues and challenges of maturity models concerning industry 4.0	Vijaya Kumar, N., Karadgi, S., Kotturshettar, B.B.	IOP Conference Series: Materials Science and Engineering	-	1.1.	-
151	A Smartness Assessment Framework for Smart	Lee, J., Jun, S., Chang, T. W., & Park, J.	Sustainability	-	-	3.9

	Factories Using Analytic Network Process					
9	A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management	Caiado, R.G.G., Scavarda, L.F., Gavião, L.O., Nascimento, D.L.D.M., Garza-Reyes, J.A.	International Journal of Production Economics	Q1	14.3	11.6
58	A Developed Analysis Models for Industry 4.0 toward Smart Power Plant System Process	Indrawan, H., Cahyo, N., Simaremare, A., Paryanto, P., Munyensanga, P.	International Conference on Information and Communications Technology	Q1	-	-

11.5.2. SLR 2

Table 24: Third selection round scores for SLR 2

Nr.	Title	Author	Journal	P%	J%	JIF
180	How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	Journal of Manufacturing Technology Management	Q1	12.4	8.1
381	AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	Decision Support Systems	-	11.3	7
153	Value-VCA in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	Journal of Manufacturing Technology Management	Q1	12.4	8.1
159	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	Technological Forecasting and Social Change	Q1	13.7	10.9
174	Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	Electronic Markets	Q1	8.9	6
200	How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	Industrial Marketing Management	Q1	10.4	8.8
228	Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	26th International Association for Management of Technology Conference, IAMOT 2017	Q1	-	-
378	Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	PICMET 2018 - Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The Engine for Economic Growth, Proceedings	Q2	-	-
154	A data-driven business model framework for VCA in Industry 4.0	Schaefer D., Walker J., Flynn J.,	Advances in Transdisciplinary Engineering	Q1	-	-
155	On the road to digital servitization – The (dis)continuous interplay between business model and digital technology	Chen Y., Visnjic I., Parida V., Zhang Z.,	International Journal of Operations and Production Management	Q1	11.1	9.4
158	Revenue Models for Digital Servitization: A VCA Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	IEEE Transactions on Engineering Management	Q1	6.2	8.7

165	Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	IEEE International Conference on Industrial Engineering and Engineering Management	Q1	-	-
168	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	Journal of Business Research	Q1	11.2	11
173	Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	Journal of Manufacturing Technology Management	Q1	12.4	8.1
184	Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	Proceedings - 2019 IEEE International Conference on Engineering, Technology and Innovation	Q1	-	-
187	Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	Industrial Marketing Management	Q1	10.4	8.9
197	Digital business model innovation: Implications for offering, platform and organization	Simonsson J., Magnusson M.,	Digital Business Models: Driving Transformation and Innovation	Q1	-	-
211	Service-oriented business models in manufacturing in the digital ERA: Toward a new taxonomy	Aas T.O.R.H., Breunig K.J., Hellström M.M., Hydle K.M.,	International Journal of Innovation Management	Q2	2.9	0.54
321	An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	Journal of Cleaner Production	Q1	15.8	11.1
352	After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	Manufacturing and Service Operations Management	Q1	9.5	7.1
390	Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant, L., Forsyth, A., Farcas, R., (...), Fan, I.-S., Shehab, E.	Advances in Transdisciplinary Engineering	Q1	-	-
405	Digital servitization business models in ecosystems: a theory of the firm	Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H. and Baines, T.	Journal of Business Research	Q1	11.2	11

11.6. Appendix 6: VCR

Table 25: VCR and additional outcomes in each of the MM phases

Phase	VCR

Zero digitalization	• Physical interaction with products/services (9)
	• Push-intensive inventory (9)
	• Unstructured logistics practices (9)
	• Manual analysis (9)
	• Corrective maintenance (9)
	• On-site inspections (9)
	• Breakdown maintenance -> (51) (408)
	    ○ Spare parts fully used (408)
	    ○ High downtime (408)
	    ○ Damaged asset (408)
	• Periodical maintenance -> Reducing downtime, excessive maintenance, wasting spare parts (9) (51) (408)
	    ○ Excessive maintenance (408)
	    ○ Reduced downtime (408)
	    ○ Waste spare parts (408)

Connecting	• Fix and maintain (148) • More secure network (148) • Remote maintenance (142) • Effective service delivery (142) • Faster support (142) • Strengthened relationship between OEM and end-user (142)

Exploring	• Evaluate individual customers on OEE (149) (142)
	    ○ Productivity (149)
	    ○ Throughput of machine (149)
	    ○ Quality (149)
	    ○ Peak loads (149)
	• Better production planning (154) (142)
	• Better utilisation (154)
	• More precise delivery dates (142)
	• Informed customers (142)
	• Faster throughput times (154)
	• Higher customer satisfaction (142)

Understanding	• Become proactive (148)

	• Up to 50% reduced downtime (408) (409) • Up to 70% reduced breakdowns (409) • Reduce maintenance costs up to 25% (148) (4) (147) (409) • Preventing waste materials (4) • Increased efficiency (142) • Maintenance hours reduced from 50 to 70% (409) • Reduced unplanned outages by up to 50% (409) • Improved product quality (4) • Improved productivity (407) • wear and tear reported → planned maintenance (142) • Improve operational performance (51) (145) (4) • In-depth understanding of end-user → fulfilling customer needs (174) (145) • Up to 12% reduction scheduled repairs (409)

Predicting	• Quicker identification of problems (144)
	• Reduced maintenance costs 5% to 10% (408)
	• Planning future production (4) (142)
	    ○ Customer delivery performance 82% → 98% (144)
	    ○ Improved on-time supplier deliveries 80% → 96% (144)
	    ○ Reduced lead times up to 50% (144)
	    ○ Reduced inventory 120 days → 80 days (144)
	• Increased productivity 4% → 5% (144) (6)
	• Improved quality (rejection rate -50%) (144) (4)
	• Factory optimization (9)
	• 36% energy savings (410)
	• Analyse unforeseen events (historical data) → optimizing future use (408)
	• 20% to 50% reduced efforts on maintenance planning (144)
	• Uptime improvement +9% to 20% (145) (408) (410)
	• Cost reduction in operations and material expenditures 5% to 12% (174) (408) (410)
	• Reduction of safety, health, environment, quality risks -14% (410)
	• Lifetime extension of aging asset +20% (410)

Simulating	• Supporting engineers in diagnosing and troubleshooting the machine (65) • Eliminate production loss (65) (390) • Optimization for different scenario's (51) • Easier identifications of vulnerabilities → offer upgrades (407) (390) • Visual (VR) help for helping operators (407) • Efficient decision making (150) • Optimization (390)

	• Improved efficiency (390) • Reduction of inconsistencies (390) • Increased quality (390) • Integration of parameters to identify impact and downtime causes (390) • Minimize manual works and reduced manpower because procedures are automated (65)
Automating	• Value added for whole ecosystem (168) • Real-time optimization (145) (58) • Operate without intervention → reduced manpower (151) (85) (142) • Quick adaptation (58) (142) • Reduced risk (148) (152) • Transforming business (148) (6) (152) • Self-optimizing (150) • Continuous improvements (150) • Occurring warning solved that are overlooked by operators (149) • Equipment switch automatically off when not needed → sustainable, minimize costs (149) • Reduce deployment costs with customized offerings (168) • Analyzing abnormalities and recovering automatically (151)

11.7. Appendix 7: Paper summary

11.7.1. SLR 1

Table 26: Summary of MMs in the final selection of SLR 1

Nr.	Title	Author(s)	Maturity levels	Description
142	Industry 4.0 Maturity Index	ACATECH; Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W.	Level 1 to 6; Computerisation → Connectivity → Visibility → Transparency → Predictive capacity → Adaptability	Presents a technical MM that is extensively described, with on every phase one or two technologies described. No or less overlap with other phases.
145	Industry 4.0: Building the digital enterprise	Pwc; PricewaterhouseCoopers	Level 1 to 4; Digital novice → Vertical integrator → Horizontal collaborator → Digital champion	MM that is not sequenced on one aspect. MM starts with multiple technologies at the same time on a low base, and upgrades towards being an expert on multiple aspects. Hard to synthesize in other MMs. High overlap with other phases.
148	Smart Machine Maturity Model	Rockwell automation	Level 1 to 4; Unconnected → Get Connected → Get Informed → Get Optimized	Extensive and practically oriented model with multiple technology descriptions per phase. Describes multiple technologies per phase with improvements and/or additions to that technology in a higher phase. Difficult to follow a clear sequence in technology.
4	Smart Factory Implementation and Process Innovation	David R. Sjödin, Vinit Parida, Markus Leksell, and Aleksandar Petrovic	Level 1 to 4; Connected technologies → Structured data gathering and sharing → Real-time process analytics and optimization → Smart and predictable manufacturing	The MM describes industry 4.0 in a minimal amount of phases. Provides clear description of technology and operations in sequential order. Does also consider people and process in describing the phases.
167	Industrie 4.0 quo vadis?	Fraunhofer ISI	Level 0 to 5; A= Digitale Managementsysteme, B= Drahtloze Mensch-Maschine Interaktion, C= CPS-nahe Prozesse / Keine Technologieen im Einsatz → Technologieeinsatz in A/B/C → Technologieeinsatz in AB/AC/BC → Technologieeinsatz in ABC → Technologieeinsatz in AB2C → Technologieeinsatz in AB3C	MM with limited explanation of phases. These phases do not come in sequential order, but are an accumulation of three aspects. The accumulated aspects are not held into consideration. Therefore, the most logical sequential order is A → B → C and is considered for further analysis.
6	Development of an assessment model for industry 4.0: Industry 4.0-MM	Gökalp, E., Şener, U., Eren, P.E.	Level 0 to 5; Incomplete → Performed → Managed → Established → Predictable → Optimizing	Presents clear sequence in technologies. Provides various key points for each phase of the MM.
152*	SIMMI 4.0 - A Maturity Model for Classifying the Enterprise-wide IT and Software Landscape Focusing on Industry 4.0	Leyh, C., Bley, K., Schäffer, T., & Forstenhäusler, S.	Basic digitalization level → Cross-departmental digitalization → Horizontal and vertical integration → Full digitalization → Optimized full digitalization	MM that does not follow a clear sequence in technologies, but rank phases based on activities. Focuses specifically on collaboration in the value chain.

149	Guideline Retrofit for Industrie 4.0	VDMA; Anderl, R., Picard, A., Wang, Y., Fleischer, J., Dosch, S., Klee, B., & Bauer, J.	VCA and visualisation → Condition monitoring → Intelligent condition monitoring → Actions	The MM provides four phases that are ordered with a strong technological influence and do not follow a clear sequence. Does not consider other concepts such as technology and has no textual description.
150*	Maturity Model for Data Driven Manufacturing (M2DDM)	Weber, C., Königsberger, J., Kassner, L., & Mitschang, B.	Nonexistent IT integration → Data and system integration → Integration of Cross-Life-Cycle Data → Service-Orientation → Digital Twin → Self-Optimizing Factory	Presents a clearly and extensively described MM. Slightly different from other MM phases in terms of technologies. Focus is here on vertical and horizontal integration.
21	To assess smart manufacturing readiness by maturity model: a case study on Taiwan enterprises	Lin, T.-C., Wang, K.J., Sheng, M.L.	Level 0 to 5; Initiated → Performed → Managed → Established → Integrated and Interoperated → Optimised	Synthesization of other MMs. Therefore, it follows the same structure in the beginning as Gökalp et al. (2017). Describes the MM in a logical order with intermediate steps, and uses terms that are not seen before.
32	The IoT technological maturity assessment scorecard: A case study of norwegian manufacturing companies	Jæger, B., Halse, L.L.	Level 1 to 8; 3.0 Maturity → Initial to 4.0 Maturity → Connected → Enhanced → Innovating → Integrated → Extensive → 4.0 Maturity	MM that is specifically designed for SMEs. Explains an extensive and well-defined path towards 4.0 maturity. Presents the steps with intermediate steps in comparison to the main stages in other models. Does not hold towards one technology, but makes several gradations in the steps.
65	An effective architecture of digital twin system to support human decision making and AI-driven autonomy	Mostafa, F., Tao, L., Yu, W.	Level 1 to 5; Basic Analytics → Data Enrichment → Advanced Analytics → Predictive Analytics → Automation	Presents a very technical and detailed MM, but only for data analytics, including digital twin. It is technology-oriented and shows a clear roadmap. It shows which technologies and resources are required towards achieving a digital twin and what value can be reached. It does not describe the whole industry 4.0 roadmap, but give detailed insights into data practices.
144	The Connected Enterprise Maturity Model	Rockwell Automation	Level 1 to 5; Assessment → Secure and upgraded networks and controls → Defined and organized working data capital (WDC) → Analytics → Collaboration	MM that functions as a clear roadmap. It defines what steps need to be taken to reach a certain phase. Phases are extensively described and practically-oriented. Does also provide other capabilities next to technology.
11	Contextualizing the outcome of a maturity assessment for Industry 4.0	Colli, M., Madsen, O., Berger, U., Wæhrens, B.V., Bockholt, M.	None → Basic → Transparent → Aware → Autonomous → Integrated	MM with clear sequencing and practical orientation.
51	A method towards smart manufacturing capabilities and performance measurement	Xia, Q., Jiang, C., Yang, C., Shuai, Y., Yuan, S.	Entry level → Low level → Medium level → High level → Expert level → Master level	MM that presents various technologies in one step, but does not provide a clear order. Hold Digital Twin into account as a part of the MM. Also describes service orientation.
85	Design of a business readiness model to realise a green industry 4.0 company	Benešová, A., Basl, J., Tupa, J., Steiner, F.	Outsider → Beginner → Intermediate → Upper intermediate → Advanced → Expert	MM is presented in a clear order, but it follows another order as the other MMs in the SLR. Focus on environmental aspects.

121	Review of research issues and challenges of maturity models concerning industry 4.0	Vijaya Kumar, N., Karadgi, S., Kotturshettar, B.B.	L1 → L2 → L3 → L4 → L5	MM with a clear order, but with minimal description of the phases.
151*	A Smartness Assessment Framework for Smart Factories Using Analytic Network Process	Lee, J., Jun, S., Chang, T. W., & Park, J.	Checking → Monitoring → Control → Optimization → Autonomy	MM focused on data analysis. Provides limited description of the phases, but a deeper insight into the steps an OEM take in data practices.
9	A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management	Caiado, R.G.G., Scavarda, L.F., Gavião, L.O., Nascimento, D.L.D.M., Garza-Reyes, J.A.	Nonexistent → Conceptual → Managed → Advanced → Self-optimized	MM describes phases extensively. It is an literature review of existing MMs, hence it has overlap with other MMs in this SLR.
58	A Developed Analysis Models for Industry 4.0 toward Smart Power Plant System Process	Indrawan, H., Cahyo, N., Simaremare, A., Paryanto, P., Munyensanga, P.	Incomplete → Initial → Manage → Defined → Quantitatively Managed → Optimizing	Limited explanation of phases. It is an literature review of existing MMs, hence it has overlap with other MMs in the SLR.

*= Retrieved by snowballing method

12.7.2. SLR 2

12.7.2.1. VCA

Table 27: Summary of VCA factors from final selection of SLR 2

Nr.	Title	Author(s)	Value capturing
180	How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	Shared revenue model → limit contractual complexity • Revenue model with a gain from sharing risk • Bonus system → share of revenue increase for outcome levels for customer • Sharing a percentage of the use/outcome revenues with partners to tie ecosystem actors more closely to their business models. • Free access to data and infrastructure → share of revenue generated from that data • Outcome-based contracts for all actors • Performance-based BM: For availability of the equipment and increase production time. For maximizing lifetime and reduce possible downtimes. • SLA for making ownership of machine simple. Lower cost based on guaranteed run hours and to determine the role distribution and responsibilities of actors regarding service levels.

381	AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	• Usage-based → periodically paying a fixed fee for access to the service • Subscription-based → charged per usage of a particular service • SLA → penalty for service provider if indicators are not met Connectivity → knowledge generation Predictive maintenance → efficient maintenance, reduced cost and higher availability

407	Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	• Subscription model
			Better cost allocation and more flexible cost sharing, improve customer loyalty, sustain competitive edge.
			  ○ Pay per use
			  ○ Pay per month
			  ○ Pay per unit
			
			In ranking from traditional to new →
			• One-off payment
			  ○ Traditional payment
			• Leasing
			  ○ Fixed free per month with option to buy later
			• Service contract
			  ○ One time buy or leasing contract, with a full package with inspections , maintance and spare part provision
			• Guaranteed availability
			  ○ Operational guarantee where the customers pays a monthly fee over the service tasks by the manufacturer
			• Monthly subscription
			  ○ No one time buy, but monthly fee where everything is included, such as service, parts and software updates. Classical subscription model
			• Usage-based
			  ○ Only pay for the machine when it is in use. e.g. airplain engines.
			• Output-based
			  ○ Only pay for the results that are generated. This can be amount of products produced, energy generated or amount of cubic meters compressed air.
			  ○ Offer upgrades with Digital Twin
			  ○ Easier selling of spare parts with Predictive maintenance
			
			Remote maintenance: quality gains.

153	Value-VCA in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	• OBP (outcome-based pricing) • PBC (performance-based contracting) • VBP (value-based pricing) • Revenue sharing
159	Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	• Subscription models • Pay-per-use • Pay-per-feature
174	Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	Condition monitoring (physical) → One-time sales Forecasting (physical and cloud) → Hybrid All-in-one solution (physical and cloud) → Hybrid Condition monitoring (physical and cloud) → Hybrid (IXON) Condition monitoring (physical) → Project Forecasting (cloud) → Time basis 1) One-time sales: the product/service is paid for only once. 2) Time basis: the product/service is paid for based on a usage period or at intervals (e.g., subscription or license for one year). 3) Project: the service is paid within the scope of a project. After the project there are no further costs charged for the service provided or for owning the output 4) Usage basis: the service is paid on the basis of the amount of services used, the computing needs and the number of uses 5) Hybrid: the combination of two or more payment models
200	How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	• *"hardware plus" logic*: add customer value to physical products through digital features. Customers purchase these features during the usage period, in order to expand product capabilities. • *Licenses*: For example with different functionality-level options, valid for a fixed period of time. • *Subscription models:* Charging customers on a recurring basis. • *Freemium models*: Companies sell offerings with selected free digital capabilities, that some customers will upgrade to fee-based premium features. Companies can also offer customers a free trial with a payment after a certain time.

			• *Usage-based* or *pay-per-use models:* Charging customers according to a certain metric. For example usage time. • *performance-based* or *pay-for-performance* models: Charge customers for the performance of an asset. • *Smart service contracts → Guaranteed customers outcomes*: e.g. asset availability, asset performance or overall efficiency increases.

228	Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	• Cloud-based BM:
			  ○ Pay-per-use
			  ○ Subscription fees
			• Process-oriented BMs
			  ○ Licenses
			  ○ Higher prices possible

378	Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	*Processing time reduction*: CPS solutions ensure decreasing errors, reduced troubleshooting time and minimized lossed from errors. • Profit = number of additional processing steps (#/year) × working time per processing step (hours/#) × hourly wage of employees and/or hourly operation expense of machines (€/hour) *Error cost reduction (real-time monitoring)*: Processing steps can be eliminated, capacity occupation of employees is reduced. • Profit = number of errors × reduction by CPS (%) × [(troubleshooting time per error × hourly wage of employees) + losses resulting from errors] *Resource consumption reduction:* Savings on raw material,and consumables, depreciation prevention and inventory cost reduction • Profit = (stock without CPS (€) - stock with CPS (€)) × interest rate (%)
408	Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	Spare part management by predicting when a component fails. For active selling, ease logistics outside office hours.
154	A data-driven business model framework for VCA in Industry 4.0	Schaefer D., Walker J., Flynn J.,	• Subscription • After-sales service • Asset sale • Usage fee

158	Revenue Models for Digital Servitization: A VCA Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	Usage-based model
			Performance-based model
			Value-based pricing
			
			These are standard models, but customization needs to be kept in mind. Therefore, design principles for revenue models are made:
			
			Design principles for value capturing:
			• Micro processing: focus on individual customer needs and derive service offering, instead of full package
			• Cocreation with customers: so that digital services match revenue model
			• Risk and reward sharing
			• Continuous adaptation of revenue model
			• Explore willingness-to-pay
			• Matched performance criteria with operational risks
			• High degree of customization
			• Matching revenue with cost structure
			  ○ subscription
			  ○ pay-per-use

165	Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	• Service as a add-on
			• Performance-based payment
			  ○ Usage behavior
			  ○ Performance level
			  ○ Performance result

168	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	**AI** • Preventive maintenance contracts: Service contracts that include early warning, productivity gains and reduction in the number of breakdowns based on AI. AI enabled advanced monitoring and controlling equipment with a digital dashboard. • Sales staff can use AI insights to offer a service agreement based on the usage period. For example, customers that use the product less frequent in a certain period can be offered a cheaper service agreement, and vice versa • Prescriptive service contracts are based on simulation models that are constructed with data of various customer sites. This enables to offer optimizing features so that OEMs can instruct customers to make the most out of their machine. For example, this can take form of suggestions on how to improve machine performance or scheduling maintenance.

173	Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	• pay-per-use • pay-per-feature
184	Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	**Digital shadow** With a subscription model of the digital shadow, the company can continuously redesign their service.
187	Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	• Product provider: Standardized products and add-on service; equipment supplier • Industrializer: Modular product offerings; service level agreements (SLA) ; System supplier • Solution provider: Customized product-service systems; performance guarantees;. Provision of availability. ; Availability provider, system integrator • Outcome provider: Customized product-service systems owned by the OEM; Performance provider → outcome business model (OBM) • Platform orchestrator: Service-dominant business model, enabling provider–customer interactions and sharing services. ; Platform business model Product manufacturer → Add-on services → Service agreements → Industrializer strategy → Solution provider → Risk/reward sharing → Outcome pricing → Outcome provider → Platform pricing → Platform provider strategy
321	An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	**Focus on sustainability** • Solution provider for complex equipment: provision on agreed results; distress users from buying high risk and costs. Performing maintenance and reducing amount of spare parts are benefits. • Complex equipment: active preventive maintenance; leased equipment by integrated service contract with various users. • Identify underutilized material → lease it to others that need it urgently → reduce wastage and improve utilization rates → dynamic leasing contracts

352	After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	• Outcome-based contracts; depending on performance of an asset • Pay-per-repair contracts • Performance based contracts; Pay-for-uptime of the machine as outcome of the overall service. Better alignment of after-sales supply chain interest. Contracts condition monitoring: In a LTSAs, the customer owns ownership of the machine, but agrees to outsource its maintenance to the manufacturer. Flexible: *PB maintenance contracts;* A type of LTSA where the maintenance contract is an uptime incentive of downtime penalty, e.g. customer fee per unit uptime or “a fee per hour of operation”. Fixed: A time-based fixed payment such as a monthly or quarterly fee.
390	Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant, L., Forsyth, A., Farcas, R., (...), Fan, I.-S., Shehab, E.	
406	Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	Smart value contract: Revenue sharing option, more dimensional perspective and direct incentives. From traditional performances warranties to: Guarantee 4.0 Smart Value contract: baseline establishment, normalizing to baseline. For example: availability +3%, output +4%, maintenance -2%, consumption -1,5%. → Performance-based contact, risk and success share
142	Industry 4.0 Maturity Index	Schuh, G., Anderl, R., Gausemeier,	Additional services

		J., Ten Hompel, M., & Wahlster, W.	
409	Time to listen to your machines	IBM	Cost reduction for OEM
410	Predictive Maintenance: Beyond the hype	PwC	Cost reductions for OEM

12.7.2.2. Use cases

Table 28: Use cases described in papers from SLR 2

Title	Author(s)	Use case
How Can Large Manufacturers Digitalize Their Business Models? A Framework for Orchestrating Industrial Ecosystems	Sjödin D., Parida V., Visnjic I.,	Risk of breakdown message with AI for a performance guarantees. AI-trigger flows into system to change spare part levels, staff scheduling re-routing of service plans
AI-based industrial full-service offerings: A model for payment structure selection considering predictive power	Häckel B., Karnebogen P., Ritter C.,	-
Digitalization as a growth driver in after-sales service: A new Lease on Life for Machine Manufacturing	Deloitte	Heidelberger Druckmaschinen are offering a output-based subscription model, with the amount of pages printed. Additionally, they increase sales with consumables (consumables as a service) and with after-sales services. This increases the cash flow and increased flexibility. The consumables and spare parts are already in the subscription, so there is more reliability for customers in budgeting and forecasting. It is possible to recognise downtime and usage to target customers with specific services, training or upgrade deals. High transparency: Makes it easier to know which spare-parts are sold. This can prevent customers from skipping the manufacturers service.
Value-VCA in digital servitization	Agarwal G.K., Simonsson J., Magnusson M., Hald K.S., Johanson A.,	-

Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0	Müller J.M., Buliga O., Voigt K.-I.,	One company recieves every morning an e-mail with production status-quo, bottlenecks and output. It is expected to improve speed, reaction and flexibility. They enabled eased customer contact and order placement: Suppliers are invited to participate on such platforms and list their prices. When the price is above the customer's expectation, no customer contact takes place. In such automated processes, human interference is low, which increases the efficiency of order placement and the cost transparency. Better customer contact and placing of orders. An automated market is risen, where all stakeholders put their price and actor can buy or not. → transparancy.
Predictive maintenance as an internet of things enabled business model: A taxonomy	Passlick J., Dreyer S., Olivotti D., Grützner L., Eilers D., Breitner M.H.,	-
How to convert digital offerings into revenue enhancement – Conceptualizing business model dynamics through explorative case studies	Gebauer H., Arzt A., Kohtamäki M., Lamprecht C., Parida V., Witell L., Wortmann F.,	Hardware plus: Revenue indirectly enhances by increased sales in equipment and sales. That is because customer value improves, what will differentiate the service delivered to the customer. Outcome based or performance-based BM: Demanding outcomes by improvements, guarantees on availability, usage and uptime. Performance guarantees such as 98% train availability improves capacity utilization in service company and decreasing service costs. This enables new recurring revenues as pay-per-use and pay-per-performance. Software BM (freemium): Food processing company uses digital technologies for monitoring kpi's. Revenue is generated by offering customers a free version of the possibilities so that customers experience the benefits. After trial, they are offered a subscription. Platform BM's: A wind turbine equipment manufacturer mixes hardware plus, subscription and guarantees to generate revenues. Additionally, the platform increases the efficiency of all assets. It enables a partner ecosystem program with benefits such as co-investments and revenue-sharing models to help partners accelerate their VCR on the platform. Additionally, the company increases revenues through revenue sharing.

Innovative business models for the industrial internet of things	Arnold C., Kiel D., Voigt K.-I.,	-

Return on CPS (RoCPS): An evaluation model to assess the cost effectiveness of cyber-physical systems for small and medium-sized enterprises	Burggraf P., Dannapfel M., Bertling M., Xu T.,	Forklift use-case:
		• Reduced processing time
		  ○ Increased productivity
		• Revenue of reduced error costs
		  ○ Decreasing error rates
		  ○ Reduced rework time
		• Revenue of reduced resource consumption
		  ○ Saved equipment
		  ○ Reduced storage cost
		• Revenue by improved information acquisition
		  ○ Further utilisation possibilities

Predictive Maintenance: Taking pro-active measures based on advanced data analytics to predict and avoid machine failure	Deloitte	-
A data-driven business model framework for VCA in Industry 4.0	Schaefer D., Walker J., Flynn J.,	Pirelli uses data to improve tire designs. Also for creating revenue through the sale of maintenance that aim to minimize downtime. Caterpillar will use sensors data to inform a maintenance schedule revenue stream, which uses data analytics for maximizing the lifespan and efficiency of equipment that is deployed. General Electric is capturing value from the process to identify opportunities, and making equipment more productive and efficient. They now offer complete customer solutions by installing equipment with specified requirements for an extended timeframe.
Revenue Models for Digital Servitization: A VCA Framework for Designing, Developing, and Scaling Digital Services	Linde L., Frishammar J., Parida V.,	Proactive service agreement ProAct 2.0 offers optimized equipment uptime by providing proactive maintenance and spare-part management

Industrial Smart Services: Types of Smart Service Business Models in the Digitalized Agriculture	Kampker A., Jussen P., Moser B.,	Simulating: Decision supporter BM: Analyzing data lead to information for the customer. For example, a digital potato experience too much shocks in the machine, a recommendation can be made for correcting machine parameters. This increases value and can be used for different BMs than only machine selling. Automation: Solution provider: This solution still need to analyse the data via a digital twin. But instead of giving a recommendation on changing parameters, the machine adjusts itself. Therefore, the farmer does not have to become active himself. This business model becomes complex, also the time horizon of the product is extensive.
AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research	Burström T., Parida V., Lahti T., Wincent J.,	*Automation* Reduces operational costs: "The operational costs have been significantly reduced through AI as we have automated many interactions with customer personnel. This has led to much better quick response times and also improved monitoring and control of the equipment". (Business development manager, Beta) *Forecasting* Better usage of equipment: "We did AI analysis on our large database which includes operation data from the last five years for certain product categories. To our surprise, we were able to find new patterns of insights related to customer operational usage which our sales and service unit has totally missed. The initial idea for doing the analysis was to create some summary reports for customers, but we ended up with much more." (Technology manager, Alfa) Optimization: "Customers thought it was costly. But with many successful customer cases, we can show the numbers of how our other leading customers managed to gain from such an offering." (Digitalization lead, Gamma) "We can truly utilize the extensive data that we have been generating for higher customer value. When we moved into optimization services, we became fully engrained into customer operations, and their operational performance became our priority." Proactive action and suggestions for improvement": It has allowed us to take the next step towards autonomy with confidence. We know very well the customer operational environment and usages and, by using AI, we develop suggestions for customers and take proactive action, when necessary."
Business model innovation in small- and medium-sized enterprises: Strategies for industry 4.0 providers and users	Müller J.M.,	-

Monetizing Industry 4.0: Design Principles for Subscription Business in the Manufacturing Industry	Schuh G., Frank J., Jussen P., Rix C., Harland T.,	Output-based: Rolls Royce's: "Power by the hour" concept Output-based: Selling heat output instead of radiators. Manufacturing changes more and more to subscription models, where high investment is not needed and divided in smaller amounts. Also, registration, maintenance and service is included. The same counts for car manufacturers, who make use of leasing contracts. A printing press machine manufacturer uses a business model with 3 components: • Monthly base fee based on the required purchase quantity calculated by pre-research. Contract period is 5 years. • One-time payment of 3-5% of the value of the machine, that covers the installation and and commissioning costs. • Extra revenue generated by a fee for every paper sheet that are produced above the minimal amount of sheets. To handle with the financial status of the OEM, 3 off-balance solutions can be used: • Financing via strategic partners that take over the financing of the machine • Financing institutions that take over the financing of the machine • Machine is bought regularly by the customer.
Managing digital servitization toward smart solutions: Framing the connections between technologies, business models, and ecosystems	Kohtamäki M., Rabetino R., Parida V., Sjödin D., Henneberg S.,	-
An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode	Wang N., Ren S., Liu Y., Yang M., Wang J., Huisingh D.,	-
After-Sales Service Contracting: Condition Monitoring and Data Ownership	Li C., Tomlin B.,	-
Exploring the transition from preventive maintenance to predictive maintenance within ERP systems by utilising digital twins	Damant, L., Forsyth, A., Farcas, R., (...), Fan, I.-S., Shehab, E.	-

Establishing successful ecosystems for IIoT platforms and B2B business models	BITKOM	-
Industry 4.0 Maturity Index	Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W.	By looking and analysing the data that is retrieved by condition monitoring can additional services be one way to VCA value. The in-depth understanding of the end user makes him more attractive than the competition.
Time to listen to your machines	IBM	Condition-based monitoring • Maintenance costs (IBM) up to -25% • Breakdowns (IBM) up to -70% • Downtime (IBM) up to -50% • Cut unplanned outages (IBM) up to -50% • Scheduled repairs (IBM) up to -12% • Capital investment (IBM) -3% → -5% • Total spend on preventive maintenance up to -50%
Predictive Maintenance: Beyond the hype	PwC	Predictive maintenance • 9% Uptime improvement (PWC) • 12% Cost reduction (PWC) • 14% Reduction of safety, health, environment, quality risks (PWC) • 20% Lifetime extension of aging asset (PWC)

11.8. Appendix 8: Interview guidelines

11.8.1. Interview guideline for practitioners

Interview 1 (practitioner)

The first interview is designed to examine the TCP, also called the practitioner interview. This interview can be divided into five parts, each categorized by header in italics. This paragraph elaborates on the choices that were made by deriving the interview questions. This interview guideline can be seen in table 8.

Introduction:

The interview starts with a short introduction to the company from the interviewee. This is followed by a clarification from the interviewer of why this research was conducted, what the goal of the research is, and why the company is selected to participate in the interview. Thereafter, the interviewer and interviewee agree on the confidentially and recording of the interview. From here on, the recording starts whenever the interviewee agrees to do so.

The interview itself can be seen as progressive and logical (Krauss et al., 2009). It starts with warm-up questions to get comfortable (Kallio, 2016). Therefore, the purpose of the first two questions (Q1,Q2) is to ask relatively light questions to let the interviewer get familiar with the topic and agree on the terms discussed. The main reason to apply the first question here is to ensure that everyone agrees on the same terms. A reason for this is that everyone is an interpreter, because most of the researchers and the audience have their own meanings for specific subjects. Accordingly, this is one of the main pitfalls a researcher has to watch out for (Myers & Newman, 2007).

As described in the Theoretical background of this study, the term Industry 4.0 is still unclear for OEMs, which may cause confusion during the interview. The third question (Q3) is there to verify the application areas that were found in preliminary research to avoid misunderstandings.

Extension of MM:

Questions 3, 4, and 5 account for the extension of the MM. Here, open questions are asked about the road to maturity that the OEM experienced. In this phase, the interviewee has not yet seen the initial framework.

Extension of business models:

In addition, questions 6 and 7 account for the extension of the business models. Here it is asked how the OEM creates value for all of the application areas that were identified in question 3. Accordingly, the interviewee is asked how they VCA the value for every application area identified in question 3.

The last question (Q8) of the extension phase is asked if the interviewee can describe a business case where Industry 4.0 is successfully implemented, and value is created and Captured. This question gives a better understanding of how the OEM uses the technology to VCA value. It adds practical applicability and extra explanation to the VCR and VCA concepts described before.

Validation of MM:

The goal of the second part of the interview is to validate the initial framework that is derived from the SLR. This starts by showing the MM and elaborate on the key concepts that describe the phases. The first question (Q9) is to ask the OEM in which MM phase they think they are participating. This accommodates the misconception bias between interviewee and interviewer, which reduces when the interviewee can assess their road towards Industry 4.0 maturity.

Questions 10 and 11 account for the validation of the entire MM from the literature. Here, the interviewee can verify if the road to maturity is similar or different from what is elaborated in the model. Questions 3, 4, and 5 have brought knowledge to the researcher about the road to maturity of that particular OEM. However, the validation part ensures that the interviewee can identify aspects that were forgotten or considered to be wrongly defined in the theoretical MM

Validation of MM:
The business model components were validated in questions 12 and 13. The OEMs solely comment on the business models in the MM phases in which the OEM participates. The validation of all business models is time-consuming and does hardly contribute to the validation process. That is because OEMs can not judge VCR and capturing that they have not experienced themselves.

Introduction

- Small talk
- Interviewee: short introduction of the company.
- Interviewer: short summary of the purpose, the goal, and the participation reasons for the interviewee.
- Asking if the interviewee permits to confidentially and recording of the interview.

Recording

1. What do you mean by Industry 4.0?
2. What is the reason you started with Industry 4.0?

Extension of MM

3. Which aspects of Industry 4.0 are you already applying in your company?
4. What steps did you have to take to get where you are today?
5. What is your vision in terms of Industry 4.0?

Extension of business models

6. What benefits have Industry 4.0 brought you and your customers for [application areas in q3]?
7. Are you able to convert these benefits into revenue? If so, what does your business model look like for [application areas in q3]? If not, why not?
8. Could you describe successful business cases? Think about application, benefits and revenue.

Validation of MM

Showing and elaborating on MM from theory

9. In which phase do you think your company is now, looking at this theoretical framework?
10. Do you think there are crucial steps that OEMs go through, or especially not go through, different as this model indicates?
11. Are certain phases necessary before starting another phase or can you do phases in parallel?

Validation of business models

Showing and elaborating on Business models from theory [in the OEMs field of application]

12. Do you experience the same benefits as indicated for each phase you went through, or are there any crucial benefits missing?
13. Have you considered the same business models, or are there any business models you do not agree with? If so, why or why not?

Figure 10: Interview guideline for practitioners (translated from Dutch)

11.8.2. Interview guideline for experts

Interview 2 (expert)

The interview for experts can also be seen in Appendix 8. It follows basically the same logic as in interview 2. All these questions are intended to retrieve the exact information from the interviewee but from a different viewpoint. Thus, the questions are formulated differently. Nevertheless, two questions from interview 1 (Q3 and Q6) do not make sense to ask companies that are not TCP, excluded these from Interview 2.

The added value of these types of interviews lies at the validation stage. That is because it is complex and intense to extend the framework from scratch for the entire Industry 4.0 revolution in phases in which the company does not actively participate. Besides, the expert has a more valuable view of the particular phases when the initial framework is shown. As a result, the framework is validated over the phases that TCP did not cover. They also have a broader view of a particular phase since they are involved with multiple TCPs, each with their own maturity path and business model.

Introduction

- Small talk
- Interviewee: short introduction of the company.
- Interviewer: short summary of the purpose, the goal, and the participation reasons for the interviewee.
- Asking if the interviewee permits to confidentially and recording of the interview.

Recording

1. What do you mean by Industry 4.0?
2. What is the reason that TCP starts with Industry 4.0?

Extension of MM

3. What steps do you see that the TCP have to take when they start with Industry 4.0 towards the end-goal of Industry 4.0 maturity?
4. What do you think that the end point of TCP is regarding Industry 4.0?

Extension of business models

5. In which way are the TCP now creating value with Industry 4.0 technologies?
6. Is the TCP able convert these benefits into revenue? If so, what does their business model look like for all of the technologies mentioned in question 3?
7. Could you describe a successful business cases you did with the TCP? Think about application, benefits and revenue.

Validation of MM

Showing and elaborating on the MM from theory

8. Do you think there are crucial steps that the TCP go through, or especially not go through, different as this model indicates?
9. Are certain phases necessary before starting another phase or is it possible to execute phases in parallel?

Validation of business models

Showing and elaborating on all the business models derived from theory

10. Do you see that the TCP experience the same benefits as described here?
11. Do you see that the TCP use the same business models in practice as described here, or are there any business models you do not agree with? If so, why or why not?

Figure 11: Interview guideline for experts (translated)

11.9. Appendix 9: Coding scheme

In this table shows six order of codes. The first four orders of codes were retrieved from the framework found in the two SLRs, via direct content analysis coding. Moreover, the fifth and sixth order codes were retrieved from the interviews, since these mostly include findings. The fourth order codes were also further complemented with high importance findings from the interviews. The last two columns contain files and references. The references column describes the number of paraphrases in that particular code, whereas the files column describes the times these paraphrases appear in an original interview.

Table 29: Coding scheme resulting from interviews

1st order	2nd order	3th order	4th order	5th order	6th order	Files	Ref.
Extension							
	Application areas						
		Automating					
			VCA				
				XaaS		1	1
			VCR				
				Self-optimization and continuous improvement		1	1
		Connecting				7	8
			Challenges				
				Security		3	3
			VCA				
				Decreasing costs		6	7
				SLA		4	6

					SLA is inherent to trouble	1	1
				Spare part management		1	2
			VCR				
				Faster support		5	7
				Minimizing downtime		3	3
				Overcoming misconceptions		1	1
				Reduced manpower		3	3
		Exploring				2	3
			VCA				
				Consumables-as-a-service		2	2
				Freemium		1	2
				Hardware and software sale		1	1
			VCR				
				Transparency on OEE		1	1
		Integrating					
			Challenges				
				No ecosystem, data islands		1	1
		No digitalization				1	1
			Breakdown maintenance			1	1
				VCA		1	1

					Pay-per-repair	1	1
					SLA	1	1
			Periodical maintenance			1	1
				VCA			
					Pay-per-repair	1	1
					SLA (preventive maintenance schedules)	2	2
				VCR			
					Waste in spare parts	1	1
		Predicting				2	2
			VCA			0	0
				Better SLA		1	1
				Higher product sale		1	1
			VCR				
				Reducing responsibilities		1	1
				Optimizing maintenance schedules		1	1
				Reduced costs		1	1
				Reduced rejection rate		1	1
		Simulating				4	4
			Challenges				

				Misconceptions		2	3
			VCA				
				Better SLA		1	1
				Increased sales of machines		1	2
				Operator training sales		2	2
				Profit increase on smaller services		1	2
			VCR				
				Better communication and visualization		2	3
				Easier comissioning of machines		2	3
				Easier identification of vulnerabilities		2	4
				First time right		4	4
				Increased optimization possibilities		1	1
				Instruction of operators		1	1
				Transparency on components of machine		1	1
		Understanding				3	4
			Challenges				
				Not knowing what to measure		1	2
				Quantifications of increased performance		1	1
			VCA				

				Additional services		2	2
				Freemium		1	1
				Better SLA		2	2
					Enterprise model	1	1
				Project-based		1	2
				Reduced maintenance costs		1	1
				Spare part management		3	4
				Subscriptions (recurring)			
			VCR				
				Better allocation of responsibilities		1	1
				Improved operational performance		4	5
				Increased efficiency		1	1
				Increased product quality		1	1
				Reduced breakdowns		2	3
				Reduced downtime		2	3
				Reduced maintenance costs		2	2
				Reduced manpower		1	1
		General VCA					
			Higher machine sale			1	1
			Output-based			1	2

				Machines not expensive enough		1	1
	Preparation phases						
		Automation				1	1
			Need for information			1	1
		Computerizing					
			Digital processes required			2	4
			Not the right controls to read data			3	4
			Web-based applications			1	1
		Connecting					
			Get all machines connected			1	2
			Infrastructure a must for Industry 4.0			1	2
			Remote access before data logging			1	1
		Exploring					
			Decentralization of whole system required			1	1
			Required for the next steps			1	1
		Predicting					
			Data extraction before predicting			2	2
		Simulating					
			Connecting, monitoring, analysing and predicting before digital twin			1	1
			Everything digitalized			1	1

			Need for information			2	4
	Vision towards Industry 4.0						
		Automating				1	1
		Not in initial framework					
			Unburden the customer			1	1
		Predicting				2	2
			VCA				
				Additional services		1	1
		Simulating				1	2
		Understanding				3	3
Validation							
	General VCA						
		Pay-per-use				1	2
	Maturity phases						
		Automating				8	8
			Far, but not unreachable			1	1
			VCA			1	2
			VCR			1	1
		Computerizing				8	9
			VCA			2	2

				No business model		1	1
			VCR			1	1
		Connecting				8	9
			Remote access without digitalization			1	1
			VCA			8	8
				SLA		3	3
			VCR			8	8
		Exploring				8	8
			VCA			3	3
			VCR			4	4
				Sustainability benefits		1	1
		Integrating				8	8
			VCA			1	1
			VCR			1	1
		No digitalization				8	8
			VCA			7	7
			VCR			8	8
		Predicting				8	8
			VCA			3	3
			VCR			3	3
		Simulating				8	8

			VCA			4	4
			VCR			4	4
			Wrong order				
				Simulating before Connecting		1	1
				Simulating before Integrating		1	1
				Simulating before Predicting		1	1
				Simulating out of the model		1	1
				Simulating without data possible (with ABB)		2	2
		Understanding				8	8
			VCA			4	5
			VCR			4	6
				Humidity enhancement		1	1
				Sustainability enhancement		1	1
	Order of MM						
		Steps in parallel					
			Exploring and Understanding			1	1
			Remote access to data logging			4	4
		Subsequent steps					
			Computerization required for further steps			2	3
			Connecting required for further steps			2	2

			Exploring and Understanding before Predicting			2	2
			Exploring, understanding, predicting, integrating, simulating, automating			2	2
			Understanding, Predicting, Integrating, Simulating before Automating			1	1